The TREND IN ENGINEERING

at the University of Washington

In this issue:

GRAVIMETRY AT THE UNIVERSITY OF WASHINGTON

CITY AIR-POLLUTION REPORT

SEISMOGRAPHIC DATA RECORDING SYSTEM DEVISED

A NEW DESIGN FOR WIND-TUNNEL BALANCE SYSTEM

EFFECTS OF CERIUM ON GRAPHITE IN ALLOY CAST IRON

CHLORINATION OF OLIVINE ORE

July, 1952

Published quarterly

by

THE ENGINEERING EXPERIMENT STATION

Conjectures Concerning the Cause and Observations Upon the Phenomena of Earthquakes

ARISTOTLE *(384-322 B.C.):*

"The severest earthquakes take place where the sea is full of currents or the earth spongy and cavernous. . . . It is the confused character of these places that makes them so liable to earthquakes. A great and violent wind is developed, which would naturally blow away from the earth; but the onrush of the sea . . . thrusts it back into the earth. The countries that are spongy below the surface are exposed to earthquakes because they have room for so much wind. . . . The force wind can have may be gathered . . . also from what is observed in animal bodies. Tetanus and spasms are motions of wind, and their force is such that the united efforts of many men do not succeed in overcoming the movements of the patients. . . . It has been known to happen that an earthquake has continued until the wind that caused it burst through the earth into the air and appeared visibly like a hurricane."*

THE VENERABLE BEDE *(673-735 A.D.):*

"Other authorities attribute earthquakes to that sea beast which lies in the ocean wrapped around the world holding its tail in its mouth. . . . This Leviathan . . . when scorched by the sun struggles to seize the sun . . . and shakes the very earth."†

VARENIUS *(1622-1650):*

"Those countries which yield great store of Sulphur and Nitre, or where Sulphur is sublimed from the Pyrites, are by far the most injured and incommoded by Earthquakes; for where there are such Mines they must send up Exhalations, which meeting with subterraneous Caverns, they much stick to the Arches of them . . . where they mix themselves with the Nitre . . . which comes out of these Arches . . . and so makes a kind of Crust, which will very easily take Fire . . . [and] goes off with a sudden Blast . . . lifting up the Ground above it."†

VANUCCI *(1789):*

[The great earthquake which shook Rimini (1786)] ". . . had its origin in showers of electric fire which fell for several days from dark clouds above the city."†

REMEDIES†

GALESIUS *(1571):*

1. Placing statues of Mercury and Saturn on the four containing walls of the building.
2. Bearing patiently these troubles which cannot be avoided.
3. Places facing to the north are less shaken.
4. Caves and subterranean passages and drains whence exhalations can escape easily from the earth are believed to be safer.
5. Vaulted brick passages and rooms are safer.
6. Dwellings should not be made too high—not over 60 feet.
7. Houses should be supported by propping them up with beams.
8. During the occurrence of the earthquake people should move out of their houses and live in tents or huts made of light boards.
9. Pray to God and ask his mercy.

---

* *Meteorologica*, II, 8. Translation of E. W. Webster.
† Quoted in *The Birth and Development of the Geological Sciences* by F. D. Adams, Baltimore, Williams & Wilkins Co., 1938.

THE ENGINEERING EXPERIMENT STATION of the University of Washington was established in December, 1917, to coordinate investigations in progress and to facilitate the development of engineering and industrial research in the University. Its purpose is to aid in the industrial development of the state and nation by scientific research and by furnishing information for the solution of engineering problems.

The scope of the work is three-fold:

(1) to investigate and publish information concerning engineering problems of a more or less general nature that would be helpful in municipal, rural, and industrial affairs;
(2) to undertake extended research and to publish reports on engineering and scientific problems;
(3) to provide opportunities for graduate engineers to conduct research under conditions that will most effectively prepare them for professional service.

For administrative purposes the work of the Station is organized into nine divisions:

1. Aeronautical Engineering
2. Chemical Engineering, Industrial Chemistry
3. Civil Engineering
4. Electrical Engineering
5. Forest Products
6. Geology
7. Mechanical Engineering
8. Mining, Metallurgy, Ceramics
9. Physics Standards and Tests

The control of the Station is vested in a Station Board consisting of the President of the University, the Dean of the College of Engineering as chairman, the Director of the Station, and members of the faculty, representative of the administrative divisions. The Board determines the character of the investigations to be undertaken and supervises the work.

The Station offers a substantial number of research fellowships to highly qualified graduate students who work under the direct supervision of the faculty of the various divisions. The results of the investigations are published in the form of bulletins, technical notes, and reports. Reprints of articles by members of the engineering faculty and graduate students published in recognized technical journals are also issued by the Station. Requests for copies of the publications and inquiries for information on engineering and industrial problems should be addressed to the Director, Engineering Experiment Station, University of Washington, Seattle 5.

July, 1952

The TREND IN ENGINEERING

at the University of Washington

Vol. 4 No. 3

Published quarterly in January, April, July, and October, by the Engineering Experiment Station at the University of Washington to reflect the current highlights of its accomplishments and to report progress in its program of investigation and research.

ENGINEERING EXPERIMENT STATION BOARD

Chairman.....Harold E. Wessman
Dean, College of Engineering

Director of the Engineering Experiment Station.....F. Burt Farquharson

Secretary.....W. W. Philbrick

DEPARTMENT REPRESENTATIVES

Aeronautical Engineering.....F. S. Eastman
Chemical Engineering.....R. W. Moulton
Civil Engineering.....R. B. Van Horn
Electrical Engineering.....A. V. Eastman
Forestry.....B. L. Grondal
Geology.....G. E. Goodspeed
Mechanical Engineering.....B. T. McMinn
Mineral Engineering.....D. A. Pifer
Physics.....J. H. Manley

PUBLICATION COMMITTEE

F. B. Farquharson, R. G. Hennes, B. L. Grondal, W. R. Hill

Editor.....Isabel W. Hemenway

PUBLICATION OFFICE

127 More Hall
University of Washington
Seattle 5, Washington

Entered as second-class matter March 7, 1949, at the post office at Seattle, Washington, under the act of August 24, 1912.

CONTENTS

Gravimetry at the University of Washington
John W. Jones 5

City Air-Pollution Report Released
Richard G. Tyler 7

Seismographic Data Recording System
A. B. Jacobsen and *LeRoy Barter* 9

Third Biennial Sewage Works School 12

Design for a New Balance System for the Kirsten Wind Tunnel *Louis B. Gratzer* 13

New Concrete Block Test Demonstrated Before Experts 16

Effects of Cerium on Graphite Formation in Alloy Cast Iron
Edward A. Rowe and *Howard A. Johnson* 17

Chlorination of Olivine Ore
H. H. Greenfield and *R. W. Moulton* 22

Engineering Research Dividends 25

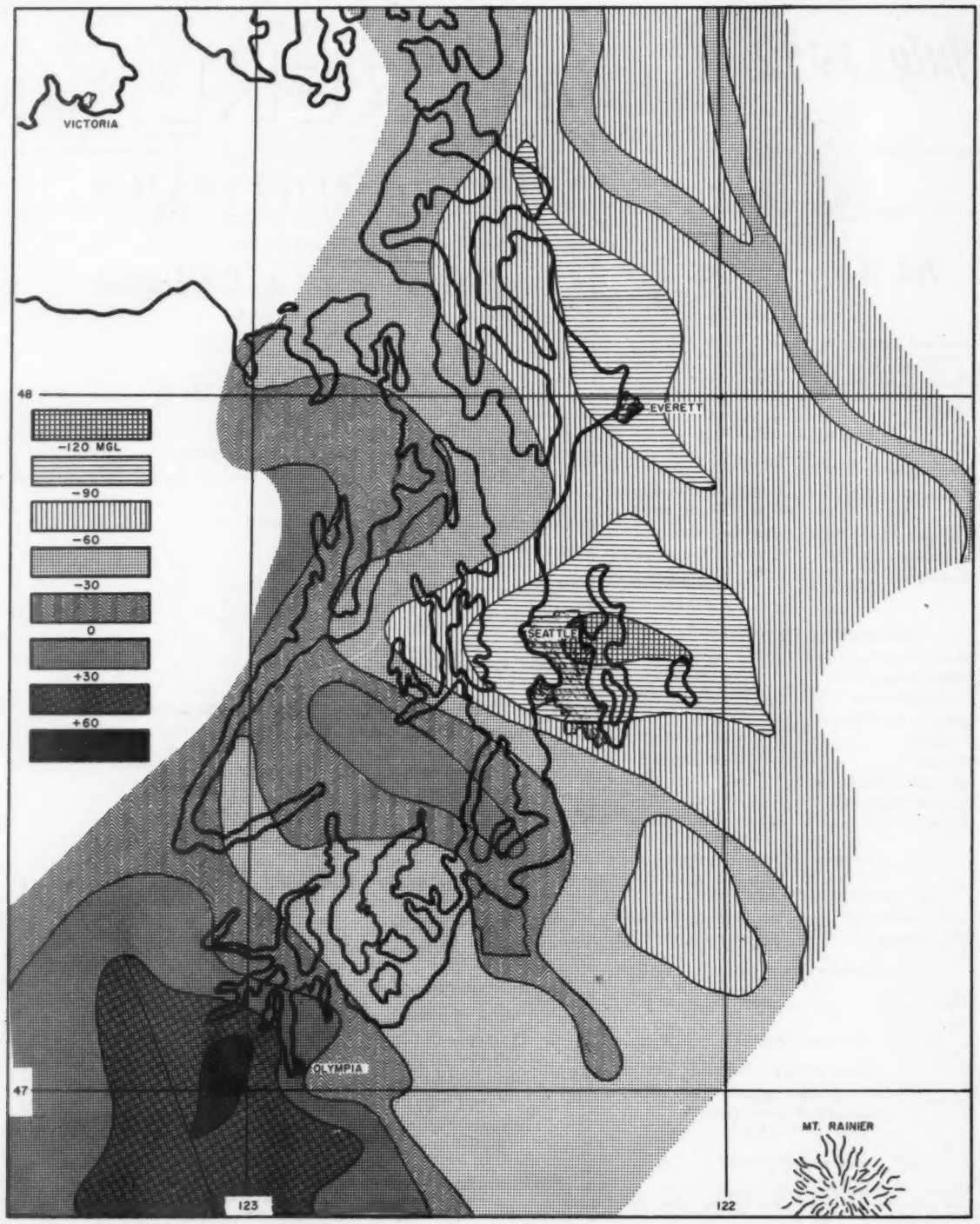
Microwave Mirrors *G. M. Russell*

Limitations of Large Turning Angle Cascades of Airfoils for Flow Diffusion *R. H. Smith*

Design and Construction of a Small Free-Piston Compressor *R. B. McKee*

Lateral Buckling of Simply-Supported Rolled Steel Beams *J. L. Tiedemann*

Engineering Professors Retire After Long Service 26



MAP SHOWING FREE-AIR GRAVITY ANOMALIES IN THE PUGET BASIN OF WESTERN WASHINGTON

Gravimetry at the University of Washington

JOHN W. JONES
Assistant Seismologist, Department of Geology

J. W. Jones

The technique of gravimetric exploration is one which is second in importance only to seismic methods in the study of geologic structure by indirect methods. In gravimetric surveys the measured or observed force of gravity is compared with a theoretical force of gravity in the following way. The theoretical gravity at any given spot is computed from the mass and shape of the earth and corrected for local elevation and topographic effects. The actual force is measured at the same location by means of a gravimeter. Anomalies, differences between measured and theoretical gravity, are explained in terms of geologic structure. In this way the underground structure of areas in which the bedrock is concealed may be determined. Gravimetric exploration methods are applicable not only to near-surface features, but to the study of variations in the structure of continents.

Most modern gravimeters are capable of being set up and read within five minutes. Some are portable enough to be carried on a man's back, although the usual mode of transportation is in an automobile. Gravimeters measure relative variations in gravity at different locations by comparing differences in the "pull" of gravity on a fixed mass. The differences are read by means of a micrometer dial coupled to a sensitive spring or torsion system supporting the fixed mass. Gravity is normally read to one-tenth of a milligal, a unit equivalent to 0.0001 dyne.

The instrument used by the Department of Geology at the University of Washington (Fig. 1) was donated to the department by the Robert Ray Geophysical Company of Houston, Texas. It is a typical spring-type gravimeter very similar to a vertical component seismograph. The fixed mass (*A* in Fig. 2) is a bar hinged to swing vertically. The bar, or boom, is suspended by two springs, one vertical (*B*), and one diagonal (*C*). The diagonal spring serves the purposes of suspending most of the weight of the boom and of increasing its sensitivity to vertical forces. The vertical spring is extremely delicate and is coupled to a calibrated dial (*D*), which measures the spring tension. Readings of gravity at different locations are made by comparing differences in spring tensions by means of the calibrated dial. The free end of the boom is adjusted to the same point at each gravity station and changes in gravitative "pull" are read on the dial. The instrument, which must be kept at constant temperature, is dependent on an ordinary 6-volt battery for operation of its heating and optical systems and, together with its protective case and battery, is transported from station to station in a panel truck.

FIG. 1. FROST GRAVIMETER

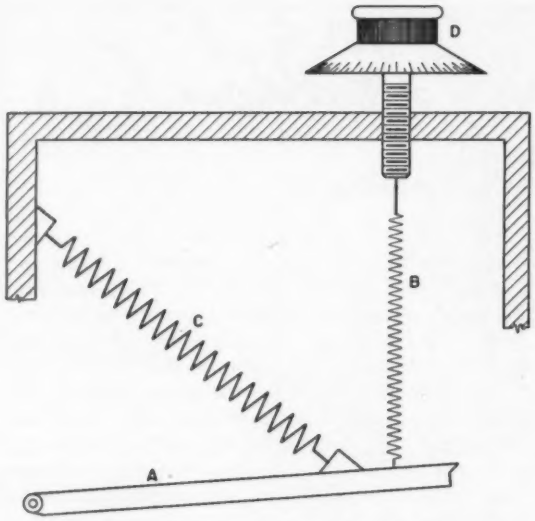


FIG. 2. SCHEMATIC DIAGRAM OF A SPRING GRAVIMETER

In 1951 the University of Washington Department of Geology began a regional study of the magnitude and distribution of gravity anomalies in the state of Washington. Gravity observations are now being made at intervals of five to ten miles along traverse routes spaced approximately fifteen miles apart throughout the state. The 350 observations already made in the Puget Basin area are only the first of approximately 2,000 stations to be established in Washington and adjacent areas. The program will take at least two and one-half years for completion.

During the period 1891 to 1951 fewer than 50 gravity observations were made in Western Washington. Anomalies found at these stations indicated the presence of some of the largest negative and positive gravity anomalies in the United States. The data collected during the initial part of the present gravity program have confirmed the early observations and revealed a very interesting pattern of gravity variations. At this time the data have been reduced only to Free-Air anomaly form. That is, theoretical gravity has been corrected only for elevation in determining anomalies. However, since the general relief of the survey is low, the topographic correction will alter these anomalies but little.

The magnitude and the abruptness of change of the anomalies (shown in the frontispiece map) are indicative of large disturbing masses of rock close to the surface of the earth. Preliminary correlations indicate definite relationships between surface geology and the anomalies. The anomalies are too large, however, to be explained entirely by superficial geologic structure. No detailed correlation of anomalies to surface geology has been made as yet; this project will be undertaken in a later phase of the gravity program.

The relationship of anomalies to earthquakes has been one interesting development in this study. The line of maximum seismic activity extends through the center of the Puget Basin along a north-south line closely following the deep negative anomaly depressions shown on the map. The negative "hollows" at Seattle, Everett, and to the north of Everett are locations where seismic activity has been concentrated in the past. The area where the anomalies change from strongly negative to strongly positive in the vicinity of Olympia is the site of another concentration of seismic activity. To the east of the axis of the basin at locations of less pronounced negative "hollows" or eastward extensions of the large anomaly depressions, minor concentrations of earthquakes occur. This evidence certainly indicates that the earthquakes are related to the large variations of gravity. Since large blocks of rock displaced from their normal positions in the earth's crust by regional forces are one cause of gravity anomalies, we might well expect the anomalies to have a relationship to earthquakes, which are manifestations of such forces.

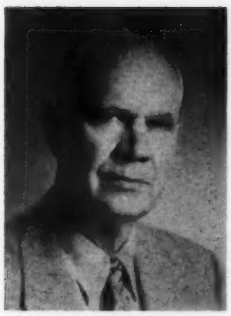
Although work on this gravity research program has only begun, it is apparent that Western Washington is an area of extreme interest from the standpoint of regional geologic structure. The presence of large mountain masses on either side of a lowland in an area of active crustal deformation makes possible the study of relationships between geologic structure and gravity anomalies under widely varying conditions. At few accessible sectors of the globe can be found such ideal conditions for regional gravimetric research as exist in the state of Washington.

PART III OF SUSPENSION-BRIDGE REPORT OFF PRESS

Part III of Bulletin No. 116, *Aerodynamic Stability of Suspension Bridges*, by F. B. Farquharson, entitled "The Investigation of Models of the Original Tacoma Narrows Bridge Under the Action of Wind," is ready for limited distribution. Libraries which received Parts I and II will receive Part III immediately, without special notice. Requests from other readers of *The Trend* for single copies will be filled in August, insofar as the number permits. A few copies of Parts I and II are still available. There is no charge.

City Air-Pollution Report Released

RICHARD G. TYLER
Professor of Sanitary Engineering



R. G. Tyler

In *The Trend* for April, 1952, Ross N. Kusian, in describing the various activities of the Environmental Research Laboratory being carried out under his direction, discussed in some detail the various studies then in progress on the Seattle air-pollution investigation. Now that the report has been submitted to the City Engineer, Ralph W. Finke, at whose request the study was made, a brief summary of the findings and recommendations made therein may be of interest to the readers of *The Trend*.

The air-pollution problem is both local and regional in nature. Locally, smoke, fumes, and dust originate principally in two major industrial districts, one lying south of Jackson street and the other extending along the Ballard-Lake Washington canal and along the shores of Lake Union. Thus industry has an industrial axis extending in a general northwesterly-southeasterly direction for almost the entire length of the city's major dimension, with some attenuation in the retail business district. Seattle is unfortunate in not having expert planning advice in localizing its industrial development in accord with a more concentrated and logical plan. The limited area still available for industrial development in and adjacent to Seattle should make its air-pollution problems easier to control in the future than in some other Washington cities having larger areas available to industry.

The regional aspects of the problem arise from the fact that with the anticipated increase in industrial development of the Puget Sound Basin, a greater blending of the air pollutants of its cities and towns will occur. Viewed from a plane 2,000 or 3,000 feet over Seattle, industrial smokes from Bellingham, Everett, Seattle, Tacoma, Shelton, Port Ludlow, and Port Angeles, may be seen flowing southward or northward depending upon the seasonal wind directions. Seattle gets both smoke and

(Continued on page 27)

FIG. 1. AERIAL VIEW LOOKING EASTWARD OVER TACOMA, JUNE 20, 1951
Top of Smog Bank Probably About 2500 Ft. Elevation

FIG. 1. *(Left):* REAR VIEW OF AMPLIFYING EQUIPMENT WITH W. G. WALKER, ELECTRONIC TECHNICIAN

Upper chassis contains the three plug-in channel amplifiers.

Lower chassis contains power supply and plug-in oscillator unit.

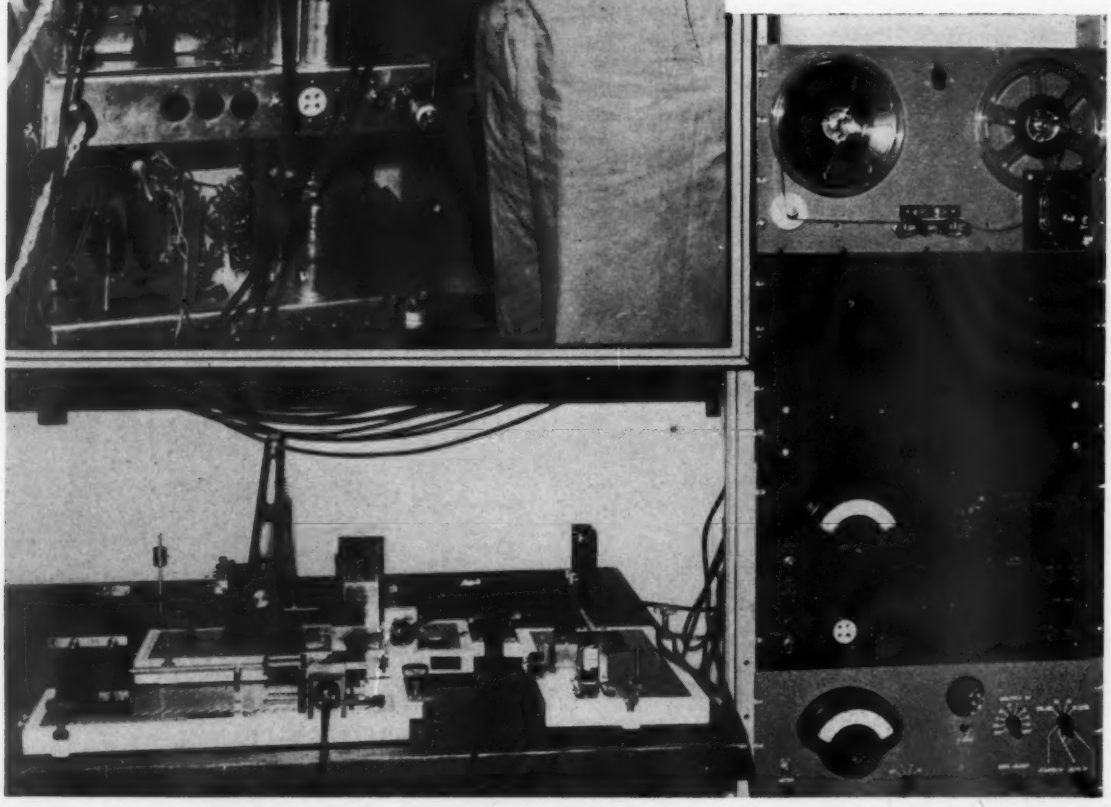


FIG. 2. *(Below):* HORIZONTAL AND VERTICAL SEISMOGRAPHS AND FRONT VIEW OF AMPLIFYING EQUIPMENT

Upper panel: Recording equipment

Middle panel: Carrier amplifiers

Lower panel: Basic amplifier used for power supply

(Just visible at bottom is a basic amplifier used to monitor equipment operation.)

SEISMOGRAPHIC DATA RECORDING SYSTEM

A. B. JACOBSEN
Instructor in Electrical Engineering

LEROY BARTER
Junior Research Engineer

A. B. Jacobsen

A system for recording, storing, and presenting seismographic data has been developed for the Geology Department of the University of Washington by Project No. 28 of the Engineering Experiment Station. This system has a number of unique features which will provide high accuracy and more flexible operation at much lower cost than present methods. Standard sound-recording magnetic tape is used to record the three components of earth displacement. This tape may be erased and re-used hundreds of times. The magnetic recording is played back for inspection at a very high speed compared with the recording speed, and significant sections of the tape may be preserved for analysis. This method which the Department has been using for the past several years required attention each day and entailed a rather high cost of photographic paper. The new data-recording system to be described here, can operate without attention up to 17 days. A higher order of time resolution is also available with this system. Figures 1 and 2 show two views of this recording system.

The Seismograph Instrument and Amplifier

In recording movements of the earth with the reference frame of the instrument fastened to the earth, one must rely upon an inertial mass staying at rest while the instrument frame moves around it. Then, since a spring type of mechanism must be used to support the inertial mass, it will determine the lower limit on the speed of the earth movement that the instrument will detect. For instance, in Fig. 3, the resonant frequency of the system is one cycle per second. A very slow movement of the earth would result in no indication in the instrument since the mass would move with the instrument frame. But if a very fast movement occurred there would be a maximum indication in the instrument. The upper limit on indicating or recording the movement of the earth is determined by the indicating or recording instrument, for it takes more energy to move a mechanical instrument, such as a galvanometer or meter needle, at a high speed than it does at a low speed. Recording on magnetic tape also has a similar limit since it involves placing a north and a south magnetic pole close together. But since this is a limit in distance on the tape between the north and south poles, the upper limit for recording earth movement will be proportional to the speed of the magnetic tape. Now, when the recorder and seismograph work together there will be a bounded frequency range of earth movements for which the system will produce a record. This is called the band pass of the system. Since the electrical energy obtained from the seismograph is so small, recording directly requires a galvanometer that has a comparatively low frequency limit (Fig. 3). But by using an electronic amplifier, either a recording galvanometer with a higher frequency limit can be used, or recording on tape can be done, resulting in a wider frequency band for the system.

LeRoy Barter

Now to show the advantages of a wide-band system consider its effect on two types of transducers. A position-sensitive transducer will give an electrical output proportional to the relative displacement (δ) between the inertial mass and the instrument frame, while a velocity transducer will give an electrical output proportional to the derivatives of δ with respect to time,

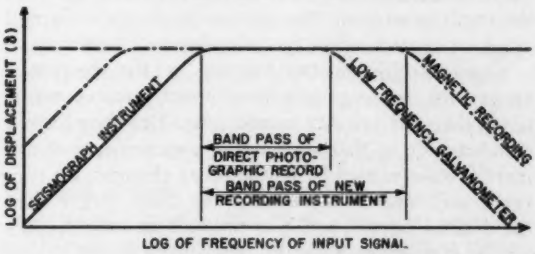

LOG OF DISPLACEMENT (δ)
SEISMOGRAPH INSTRUMENT
BAND PASS OF DIRECT PHOTOGRAPHIC RECORD
BAND PASS OF NEW RECORDING INSTRUMENT
LOW FREQUENCY GALVANOMETER
MAGNETIC RECORDING
LOG OF FREQUENCY OF INPUT SIGNAL

FIG. 3. COMPARISON OF RECORDING SYSTEMS

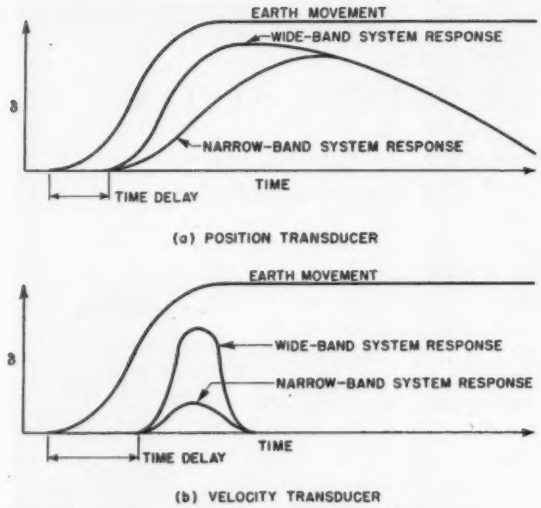


FIG. 4. RESPONSE TO STEP MOVEMENT OF EARTH

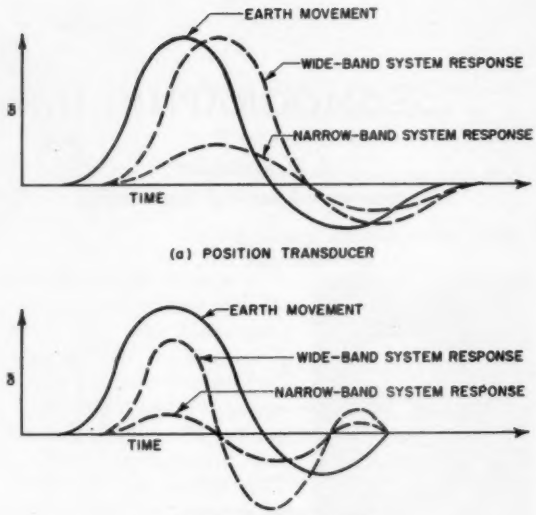


FIG. 5. RESPONSE TO VIBRATORY EARTH MOVEMENT

or $d/dt(\delta)$. Figure 4 (a) shows the effect on the response of a position transducer of a wide- and a narrow-band amplifier. After an initial time delay, the response of the wide-band amplifier will approximate the shape of the earth movement. The slope of the final decay of the recording is due to the movement of the inertial mass as it finally follows the movement of the instrument frame. Figure 4 (b) shows the effect on the response of a velocity transducer of a wide- and a narrow-band amplifier. After a similar time delay the recorded output will be proportional to the speed of the earth movement. (The initial time delay has been greatly exaggerated in the illustration to show its presence.) If all those component seismographs had similar recording systems, the delay, besides being small, would be the same in each case. Figure 5, (a) and (b), shows the responses to a different type of earth movement. This time the assumed movement is vibratory in nature. In this figure the difference in result between the position and velocity transducers is less. But in both cases the wide-band systems give larger results. If the upper limit of the narrow-band system was less than the frequency of the earth movement, the narrow-band system would show no record, while the wide-band system may.

Position-sensitive transducers in the frequency ranges for seismographs have much greater sensitivity than the velocity transducers. But they have a disadvantage in that slow random movements of the inertial mass caused by temperature changes, air currents, etc., which may actually be much larger than the desired signals, will also produce an output. This can be compensated for by a feedback circuit which tends to reposition the inertial mass but which only operates at frequencies below the resonant frequency of the seismograph.

The seismographs used in this system were built by Sprengnether Instrument Company. A Schaevitz Linear Transducer was mounted near the pickup coil of the seismograph. The pickup coil is used in the repositioning feedback circuit. Movements in the seismograph mass, or beam, modulate the amplitude of the 1,500-cps carrier applied to the transducer. This modulated carrier is then amplified and demodulated giving an output current proportional to the displacement of the seismograph beam. The current is then sent to the magnetic recording head and through a frequency selective network to the repositioning coil. The output voltage is sufficient to operate other recorders. A block diagram of the sytem is shown in Fig. 6. On the vertical component unit, a temperature control was found to be necessary (not shown in the figure). Associated with the amplifiers and demodulators are the power supplies and carrier oscillator. This equipment is shown in Figs. 1 and 2. The oscillator, as well as each carrier amplifier unit, was constructed as a plug-in assembly to facilitate servicing. The power supply of a Basic Amplifier* was used. Also shown in the photograph is a Basic Amplifier and oscilloscope attachment used on the initial time test of the equipment.

The system for the inertial component was set up on the floor of Room 228, Electrical Engineering Hall, and some recordings were made on a Brush

* See *The Trend in Engineering* for October, 1949, for a description of this basic amplifier.

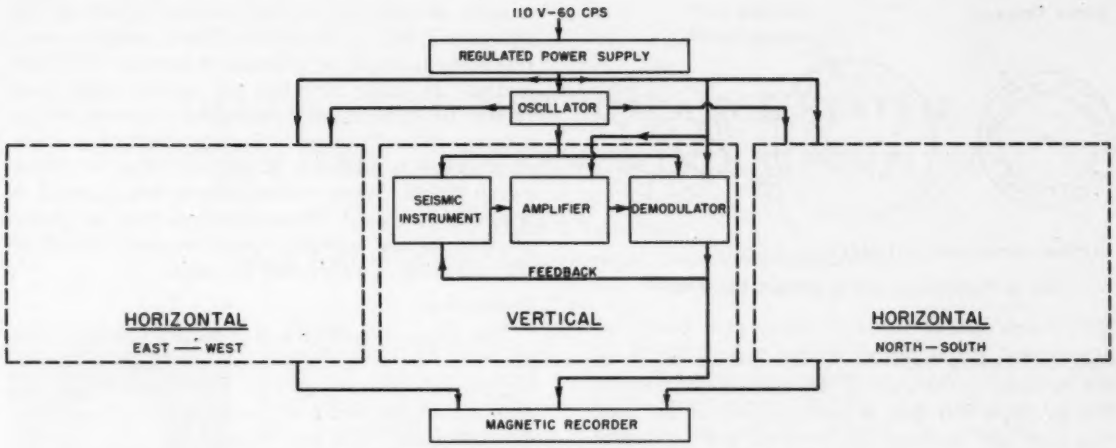


FIG. 6. BLOCK DIAGRAM OF FIELD RECORDING EQUIPMENT

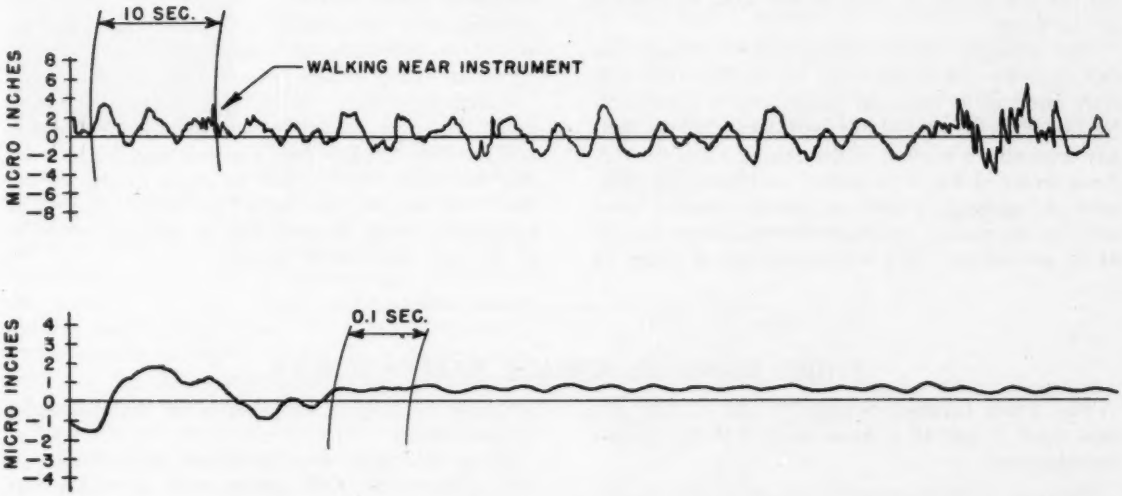


FIG. 7. TYPICAL RECORDINGS

Model BL902A paper recorder. Sample records are shown in Fig. 7. At the top is shown a record of the background noise or microseismograms. At the bottom is shown the resolution that is possible. The tape speed and amplifier sensitivity were increased. The floor was then shocked by a small pulse as shown on the record. After that the vibration in the floor reappeared periodically. The shorter period vibrations are due to the properties of the floor, while the time for their reoccurrence is the time the impulse took to go to a side of the building and return.

Magnetic Recording

Four tracks are used on ¼-in. magnetic tape at a speed of 4.5 in. per minute. Three tracks record the seismographic data and the fourth track is used for timing information including, date, hour, minute, and second. WWV Standard time transmissions from a radio receiver will also be recorded on this track to check the chronometer. Separate recording heads 0.030 in. wide are spaced at one-inch intervals along the tape and displaced laterally to provide for four tracks. Bias current for linearizing recording amplitude is obtained from the 1,500-cps carrier supply.

The complete field recording system will operate from storage batteries charged from the power line so as to assure continuity of recordings.

Playback System

Presenting the information that has been recorded on magnetic tape offers an important advantage in that time can be speeded up. Of course the

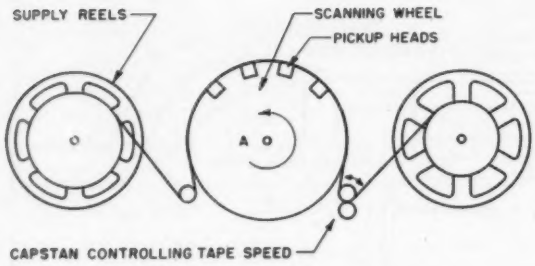


FIG. 8. TAPE-SCANNING PLAYBACK EQUIPMENT

total information could be re-recorded on paper, as will be done in the case of the desired information. But an important step is the scanning of the total recording and selecting the portions that are worth keeping. These desired portions can then be either cut out and saved, or recorded on paper and saved in that form.

The scanning method planned is to present the tape-recorder information on an oscilloscope. But since one look at transient phenomena is insufficient for evaluation, a method has been devised to continually scan only a portion of the record when desired. As is shown in Fig. 8, Wheel A, containing the magnetic pickup heads, rotates so that the relative speed between the pickup heads and the stationary tape is 45 in. per second. This will correspond to about 15 minutes of recording in one second. Advancing the tape past Wheel A will permit either continual progress along the tape, or selection of another 15-minute portion. In order to make the sweep length long enough to utilize the full resolution of the recording, a raster of ten lines for each component on a 12-in. oscilloscope is planned, giving an effect of 80-in. sweep length. When information is found which is desirable to record, the oscilloscope may be photographed, or the scanning speed changed so that an ink recording on paper may be made.

Conclusion

The system described will provide a practical solution to the technical and economic problem of operating several remotely located field stations and will permit a higher order of precision and convenience to seismometry than now is possible.

It has many other possible applications where an inexpensive data collector is desired and where time translation of phenomena is required. Proposals to record weather data, and suspension-bridge motion by means of this system have already been advanced.

Comparison tests just completed show that this system has even greater sensitivity than is necessary, and in other respects does a satisfactory job of seismic recording. Efforts will be made to extend the low-frequency response from 1 cps to 0.1 cps, so that only one seismic element will be necessary instead of the two required at present.

THIRD BIENNIAL SEWAGE WORKS SCHOOL

The Third Biennial Sewage Works School was held April 17 and 18 at More Hall, with the following sponsors:

University of Washington, Department of Civil Engineering,
Division of Adult Education,
State Department of Health,
Pollution Control Commission,
Pacific Northwest Sewage and Industrial Wastes Association,
Association of Washington Cities.

Instructors were drawn from the sponsoring units and the University faculty in the Department of Civil Engineering.

The purpose of this "school" which is held alternate years in the eastern and western portions of the state, is to acquaint men in the field of waste collection disposal with the fundamental practices essential to proper, safe, and economical operation of their respective treatment plants. This year's school was intended primarily for operators and their supervisors in the western portion of the state. Previous technical training or schooling is not a requirement for attendance.

Those attending the school were divided into an "A" group and a "B" group, each of which was further subdivided in order to attain small classes for instruction. The "A" group was designed to include those who had not attended a previous school of this type or who had not previous training or instruction in this field. The "B" group was open to those who had attended a previous school of this type or who felt that their experience qualified them for more advanced instruction. Assignment to either group however, was entirely at the discretion of the individual concerned.

Topics under discussion the first day included plant arithmetic, sewage chemistry, plant hydraulics, filter biology, gas utilization, sewage treatment, sewage and sludge pumping. The second day, in addition, also included lectures on digester operation, sewage sedimentation and filter operation. Laboratory demonstrations were given each day.

Eighty-two men registered for the course.

DESIGN OF A NEW BALANCE SYSTEM FOR THE KIRSTEN WIND TUNNEL

LOUIS B. GRATZER
Junior Research Engineer, Department of Aeronautical Engineering

L. B. Gratzer

Design work on a new balance system for the F. K. Kirsten 8′ x 12′ wind tunnel was begun in January, 1951, after a preliminary planning stage of several months. This project was undertaken as part of a modernization program supported jointly by the Boeing Airplane Company and the University of Washington Aeronautical Laboratories.* The principal reason for replacing the present balance system[1] is to obtain, when desired, a clear test section. As a consequence, a more versatile mounting system will be available to handle a wider variety of wind-tunnel models and test setups. The new design will provide greater rigidity and strength which will allow the testing of larger models at higher speeds. It is interesting to note that the basic mechanism for the new design is an adaptation of that used for a three-component balance system which was designed and built at the University of Washington where it has been in operation in the Venturi wind tunnel since 1946. The design phase of the project is now virtually completed, and construction, which is being done largely in the Aeronautical Engineering Shop, is well under way.

The heart of the balance is basically a lever system which accomplishes the resolution of the resultant force on the model into six components, i.e., lift, drag, side force, pitching moment, rolling moment, and yawing moment, as indicated in Fig. 1. Reactions to these forces and moments are provided separately by six electromagnets operating in strong permanent-magnet fields. The coil current required for equilibrium is proportional to the load applied and is measured with a milliammeter. Details of the design and operation of these electromagnetic devices (called Eastman balance pots) and associated electrical equipment are given in Reference 2. The sketch (Fig. 2) shows the mechanical details of the balance system. The general arrangement was dictated somewhat by the requirement that the new system fit into the base of the present balance. In addition, it was desired that the force take-off points correspond to those now existing to permit the use of the present bell-crank and balance-pot arrangement. The lever system consists essentially of four steel tubes hinged universally at the ends by means of flexure pivots. These are used throughout the system to provide hinge points wherever required. A discussion of the

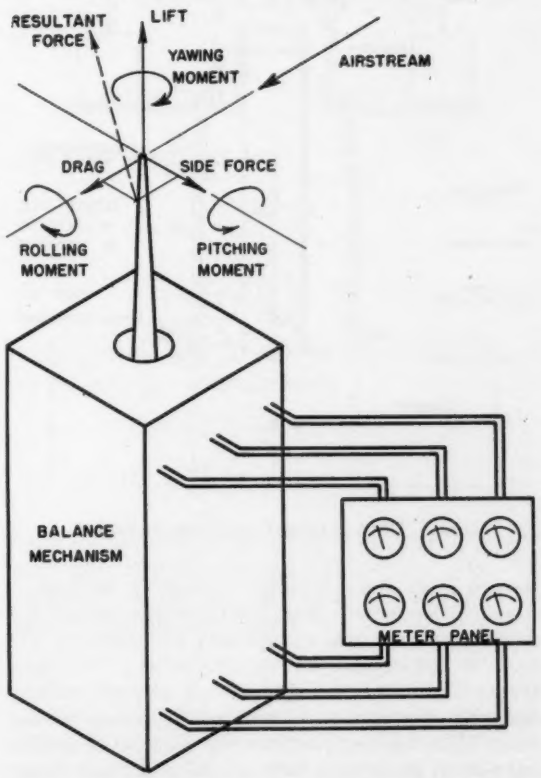


FIG. 1. DIAGRAMATIC SKETCH OF BALANCE SYSTEM

* See the April, 1951, issue of *The Trend* for details of this arrangement.

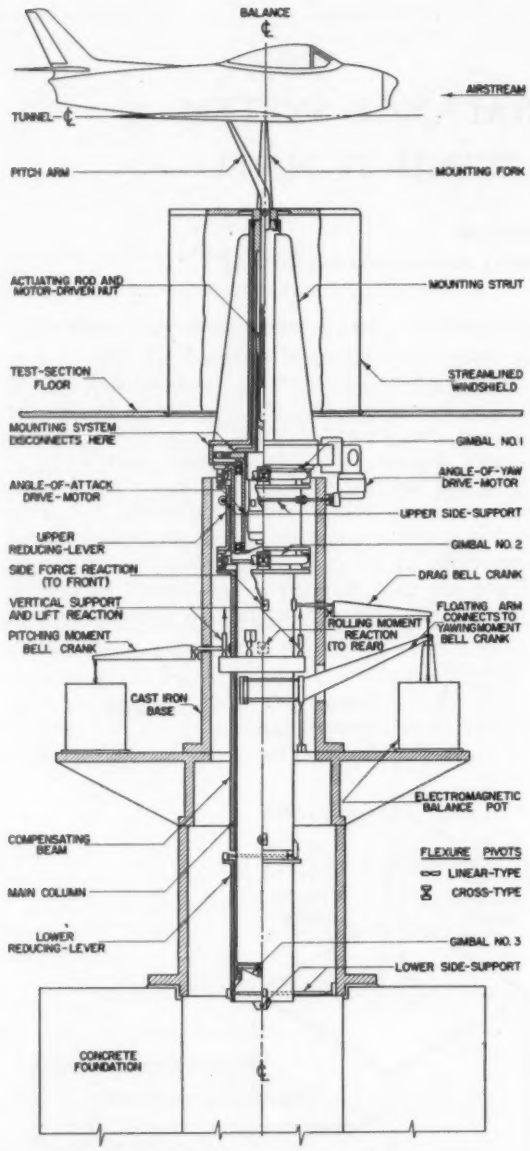


FIG. 2. DETAILS OF BALANCE ARRANGEMENT

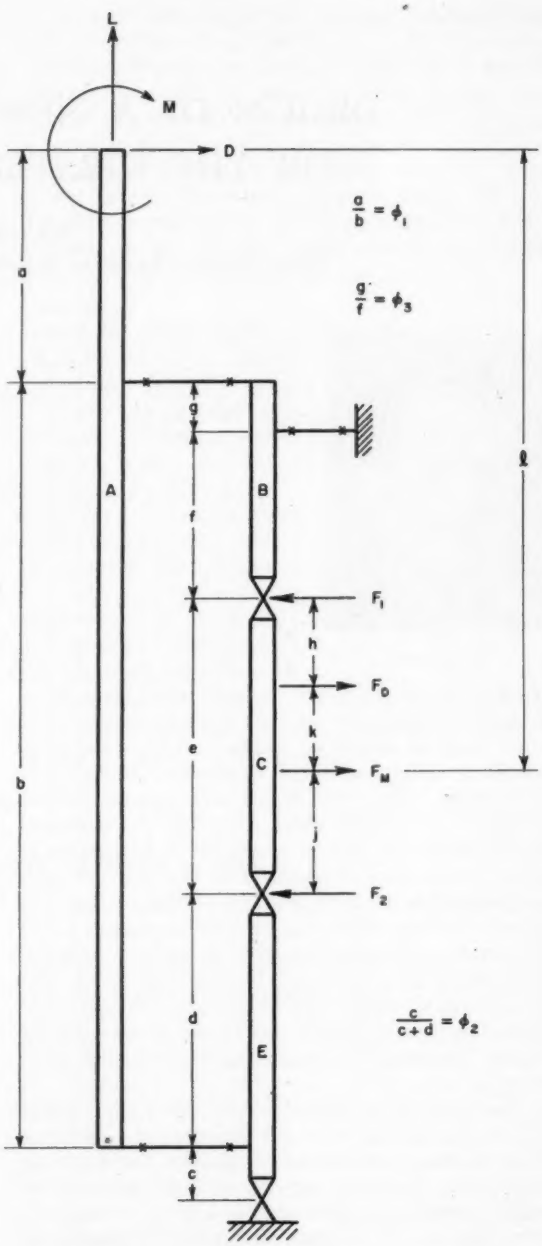


FIG. 3. SCHEMATIC DIAGRAM OF BASIC LEVER SYSTEM

flexure pivot and its design appears in References 3 and 4. The main column or inner tube carries the model and mounting system and transmits the air loads on the model to the upper and lower reducing-levers. These surround the main column and serve to transmit appropriate forces to the compensating beam. This member performs the function of resolving part of the force system on the model into forces proportional to the four components: drag, side force, pitching moment, and rolling moment. These are then transmitted directly to the balance pots through the four bell cranks pivoted on the base. The entire mechanism is supported by the upper and lower side supports and the vertical support which also serves to transmit the lift force through an intermediate

lever (not shown) to the lift pot. The yawing moment is transmitted independently to the yaw pot through a floating arm which restrains the main column in yaw only.

The model mounting system is bolted directly to the main column and is easily removable. This arrangement allows the complete removal of the mounting system to provide a clear test section for certain types of testing. In addition, other types of mounting systems may be used as desired. The model is mounted on a two-pronged mounting fork with pitch arm, and pivots about a transverse axis perpendicular to the center line of the balance system. The angle-of-attack is controlled by means of an actuating rod and motor-driven nut combination which is connected to the model through the pitch arm. The angle-of-yaw is controlled by rotating the inner member of the mounting strut about the center line of the balance system. This member is bolted to an assembly pivoted on ball bearings carried by the main column, and is driven by an electric motor through a worm and gear combination.

The theory of operation of the balance system can be readily understood by considering the basic lever system shown schematically in Fig. 3. Only that part of the system associated with the separation of drag and pitching moment components is shown. The actual balance system combines this function and the separation of side force and rolling moment in the same member, i.e., the compensating beam. Members A, B, C, and E correspond to the main column, upper reducing-lever, compensating beam, and lower reducing-lever, respectively. Note that the interconnections are made with flexure pivots; thus a perfect hinge is provided, except for small elastic restraints (cf. References 3 and 4). The rotation of each flexure pivot is so small that these effects are almost imperceptible and, generally speaking, can be compensated for in calibration of the balance. In the following analysis they are neglected since they are of second order of magnitude. The lift reaction is taken directly from member A and need not concern us further. Considering the effects of the drag and pitching moment components, it can be shown that

$$F_1 = D\left(\frac{a+b}{b}\right)\frac{g}{f} + \frac{M}{b}\frac{g}{f} = D(1+\Phi_1)\Phi_3 + \frac{M}{b}\Phi_3, \quad (1)$$

$$F_2 = D\,\frac{a}{b}\left(\frac{c}{c+d}\right) + \frac{M}{b}\left(\frac{c}{c+d}\right) = D\Phi_1\Phi_2 + \frac{M}{b}\Phi_2, \quad (2)$$

where F_1 and F_2 are forces applied by members B and D respectively to member C. Isolating member C, we find that

$$jF_2 + kF_D - (h+k)F_1 = 0$$

and

$$(j+k)F_2 - kF_M - hF_1 = 0.$$

Solving for F_D and F_M and substituting Eqs (1) and (2) we obtain

$$F_D = F_1\left(\frac{h}{k}+1\right) - \frac{j}{k}F_2$$

$$= D\left[(1+\Phi_1)\,\Phi_3\left(\frac{h}{k}+1\right) - \Phi_1\Phi_2\frac{j}{k}\right]$$

$$+ \frac{M}{b}\left[\Phi_3\left(\frac{h}{k}+1\right) - \Phi_2\frac{j}{k}\right],$$

and

$$F_M = -F_1\frac{h}{k} + \left(\frac{j}{k}+1\right)F_2$$

$$= -D\left[(1+\Phi_1)\,\Phi_2\frac{h}{k} - \Phi_1\Phi_2\left(\frac{j}{k}+1\right)\right]$$

$$- \frac{M}{b}\left[\Phi_3\frac{h}{k} - \Phi_2\left(\frac{j}{k}+1\right)\right].$$

In order that F_D and F_M be independent of pitching moment and drag, respectively, we must have

$$\Phi_3\left(\frac{h}{k}+1\right) - \Phi_2\frac{j}{k} = 0$$

and

$$(1+\Phi_1)\,\Phi_3\frac{h}{k} - \Phi_1\Phi_2\left(\frac{j}{k}+1\right) = 0,$$

or, solving for $\frac{h}{k}$ and $\frac{j}{k}$,

$$\frac{h}{k} = \Phi_1\left(1+\frac{\Phi_2}{\Phi_3}\right), \quad (3)$$

$$\frac{j}{k} = \Phi_1\left(1+\frac{\Phi_3}{\Phi_2}\right) + \frac{\Phi_3}{\Phi_2}. \quad (4)$$

Substituting Eqs (3) and (4) into the expressions for F_D and F_M, we obtain finally

$$F_D = D\,[(1+\Phi_1)\,\Phi_3 + \Phi_1\,\Phi_2],$$

$$F_M = \frac{M}{b}\,(\Phi_2+\Phi_3).$$

Thus we have two forces F_D and F_M proportional to drag and pitching moment, respectively, when the conditions (necessary and sufficient) expressed by Eqs (3) and (4) are fulfilled.

A similar analysis holds for determining the conditions required for the separation of side force and rolling moment components since their relationship, viewed in a plane perpendicular to the tunnel axis, is identical with that of drag to pitching moment in the original plane. This allows the combination of

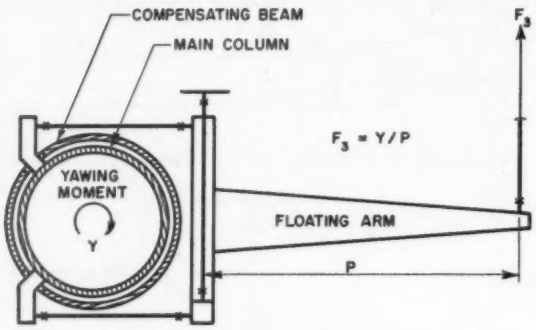


FIG. 4. YAW TAKE-OFF MECHANISM

both functions of separation in the compensating beam because the forces produced on the beam in the two planes are mutually independent.

Figure 4 is a section in plan view and illustrates the basic features of the yawing moment take-off mechanism. The floating arm is coupled to the main column in such a way as to provide only a couple to resist the applied yawing moment, Y. This is evident if we notice that the main column is free to translate or rotate in any direction except about the vertical center line of the system. The force, F_3, is proportional to yawing moment and is transmitted to the yaw pot through a suitable bell-crank arrangement. The above analysis leaves the choice of dimensions for the system rather arbitrary, and in general this will depend on the loads to be measured, the load capacity of the balance pots, and the particular physical requirements in a given case. In the present case many of the dimensions were already fixed (or variable within narrow limits) since it was desired to retain the base and external mechanism of the existing balance system.

As indicated previously, considerable attention must be given to the design of the flexure pivots since they must be strong enough to resist the maximum loads applied and flexible enough to permit necessary motion of the various members without causing perceptible errors in the final readings. In general, the main members are designed to keep structural deflections to a minimum because these can be a potent source of error. This of course results in much heavier members than would be required from strength considerations and is reflected in the weight of the system, the total suspended from the vertical support being approximately 1,500 lb.

In summary, the principal advantages afforded by the new balance system can be stated as follows:

1. Allowing the use of a clear test section which is desirable for some types of testing,
2. Availability of a versatile mounting system to accommodate a wider variety of models and test setups,
3. Greater rigidity and strength allowing the testing of larger models at higher speeds,
4. Complete mechanical resolution of the resultant force on the model into its six basic components.

It is anticipated that improvements in the wind-tunnel control arrangement and auxiliary equipment will be a major step in enabling the University of Washington Aeronautical Laboratories to continue their valuable contributions to aeronautical research.

REFERENCES

1. KIRSTEN, F. K., and EASTMAN, F. S., "The University of Washington's New 250-mph 8 x 12 Foot Wind Tunnel," *Jour. Aero. Sci.*, Vol. 6, No. 12 (October, 1939).
2. EASTMAN, F. S., "The Electromagnetic Balance—A High Precision Measurement and Control Device," *Instruments*, Vol. 14 (October, 1941).
3. EASTMAN, F. S., *Flexure Pivots to Replace Knife Edges and Ball Bearings*, University of Washington Engineering Experiment Station Bulletin No. 86, November, 1935.
4. EASTMAN, F. S., "The Design of Flexure Pivots," *Jour. Aero. Sci.*, Vol. 5, No. 1 (November, 1937).

NEW CONCRETE BLOCK TEST DEMONSTRATED BEFORE EXPERTS

Mr. Carl A. Menzel, Manager, Housing and Cement Products Bureau, Portland Cement Association, Chicago, who has developed an apparatus and a method for determining the moisture condition of concrete block in terms of relative humidity, gave a demonstration of his apparatus and method on May 26 and 27 at More Hall before an interested group which included the following:

Frank J. Barrett and Bennett Saunders of the Portland Cement Association (Seattle); Donald Herak of the Portland Cement Association (Spokane); R. G. Hennes, R. H. Meese, Martin Ekse and F. B. Farquharson of the University of Washington; E. Ellis Cummins and F. P. Scharff of the Yakima Cement Products Company, Yakima; J. A. Holroyd and Merton Crawford of the Holroyd Company, Tacoma; John Hutsell of the Associated Sand & Gravel Company, Everett; Frank Spangler, Empire Building Material Company, Portland, Oregon; and C. M. Howard, Concrete Products Association of Washington; F. M. Kettenring, Howard Anson and John James of the Graystone Concrete Products Company, and Verne Frese and Wallace Beardsley, Layrite Concrete Products, all of Seattle.

Mr. Menzel's test method provides a simple and rapid means for determining whether a block is dry enough for use without excessive shrinkage in the wall and can be completed in about twenty minutes as compared to forty-eight hours, or more, for the present standard method of test based on a total absorption.

EFFECTS OF CERIUM ON GRAPHITE FORMATION IN ALLOY CAST IRON*

EDWARD A. ROWE
Associate Professor of Metallurgy

HOWARD A. JOHNSON
Research Fellow, Engineering Experiment Station

THE STRUCTURAL ENGINEERING uses of gray cast iron have been restricted by its limited tensile strength and ductility. Recent research has shown that the mechanical properties of this metal are greatly improved if the graphite is in the nodular or spherulitic form. Processes which result in the production of nodular graphite structures in the as-cast condition involve the use of cerium or magnesium.

The problem studied and reported in this paper is the nodulizing effect of cerium on a specific cast iron.

Review of Literature

Nodular graphite structure, first observed in malleable cast iron, contrasts with normal flake structure in that the graphite is in spherulites or nodules rather than in the normal elongated-flake form. Some of the disadvantages of malleable cast iron are the section limitations and the necessity for very close composition control to permit satisfactory annealing. Carbon structures similar to those in malleable iron can be obtained in the as-cast condition merely through the use of small ladle additions of cerium.

The general action of cerium in cast iron as discussed by Morrogh and Williams[4] is first to desulphurize the melt and then to inhibit the carbide decomposition. Retardation of graphite formation until after the melt has built up interior pressure forces the graphite into the stable, spherical configuration. If the internal pressure of the melt becomes greater than that of the forming graphite, the carbon is retained as a carbide, and the cast iron is susceptible to chilling. The harsh carbide stabilizing action of cerium can be tempered by secondary graphitizing inoculants such as alloys of the ferrosilicon type.

There are three general theories of inoculant behavior. These are discussed in a paper by Lownie:[3] (1) The theory that gases cause structural changes in metals and that the inoculant acts as a degasifier; (2) the graphite nuclei theory that the inoculant facilitates the formation of graphite nuclei; (3) the silicate slime theory that foreign material is provided as a nucleus. Which of these theories is correct is not known.

Morrogh and Williams[4] state these rules for consistent results:

1. The iron must solidify gray.
2. The iron must be hypereutectic; that is, the percentage of carbon must be greater than 4.3 minus ⅓ of the combined percentages of silicon and phosphorus.
3. The silicon should be between 2.3 and 7 per cent.
4. The sulphur should be below 0.02 per cent.
5. The phosphorus should be below 0.5 per cent.
6. The effects of manganese, copper, nickel, chromium, molybdenum, and vanadium are negligible so long as the previous conditions are met.

The alloy cast iron used in this investigation was hypoeutectic of composition shown in Table I.

Three deviations from the foregoing rules are contained in Table I. The carbon equivalent of the alloy cast iron used is below 4.3 per cent, the silicon is 2.00 per cent, and the sulphur is slightly high. Carbon is the most serious discrepancy, since the carbide stabilizing effects of cerium cause susceptibility to chilling in hypoeutectic cast irons, as previously stated. The silicon deficiency is partially overcome by the presence of 2 per cent nickel, and additional silicon may be added as an inoculant. The excess sulphur is not serious to the problem although it would increase the cost, since the cerium acts preferentially and desulphurizes before it stabilizes the carbides.

TABLE I

ANALYSIS OF CAST IRON USED

Element	Percentage
Carbon	2.25–3.20
Sulphur	0.03
Nickel	2.00
Manganese	0.75–2.50
Phosphorus	0.02
Silicon	2.00
Molybdenum	1.00
Iron	Remainder

* Reproduced by permission of the American Foundrymen's Society from AFS Preprint No. 52-1 (1952). The article is based on the thesis of H. A. Johnson submitted for the degree of M.S. in Metallurgical Engineering, 1950, and the investigation was carried on as EES Project No. 59.

TABLE II

Experimental Data and Test Results

Melt	Pouring Temp., F	Cerium, %		Silicon, %		Tensile Strength			Hardness
		Addition	Retained	Inoculant*	Total	Treated Sample psi	Control Sample psi	Strength Ratio** %	BHN
A	2670	0.10	0.075	——	2.02	unmachinable		——	475
E	2720	0.04	0.027	——	1.96	61,800	67,300	91.8	300
H	2730	0.01	0.007	——	1.93	67,200	77,250	87.0	402
I	2750	0.02	0.013	——	1.93	74,700	77,400	96.5	407
M	2780	0.04	0.035	0.03	1.75	unmachinable		——	475
Q	2730	0.04	0.032	0.04	1.82	70,600	70,900	99.6	321
V	2780	0.04	0.035	0.3	2.53	73,000	79,000	92.4	363
X	2780	0.04	0.023	0.5	2.72	80,400	78,800	102.0	310
IV	2900	0.04	0.026	3.0	5.87	31,500	55,250	57.0	321
IW	2790	0.04	0.035	1.0	3.20	76,400	55,800	137.0	352
AA	2920	0.05	0.017	3.0	6.17	20,000	72,700	27.5	363
BB	2890	0.04	0.018	3.0	5.92	25,000	73,500	34.0	341
CC	2750	0.04	0.024	1.5	4.38	73,600	72,200	102.0	375
EE	2820	0.05	0.026	2.0	5.10	33,200	73,000	45.5	302
FF	2620	0.04	0.018	2.0	4.85	42,600	72,800	58.5	341

*Secondary inoculant; to melts M and Q as CaSi; to remainder as 85% FeSi.

**$\frac{100 \times \text{T.S. Treated}}{\text{T.S. (untreated)}}$ = per cent tensile strength.

Experimental Procedure

In order to minimize the possible effects of other metals, especially the rare earths, the purest cerium available was used. This analyzed 92.6 per cent cerium, 1.1 per cent iron, and the balance other rare earth metals. Misch-metal* has been suggested for commercial use provided it is magnesium-free.[4]

All test melts were taken from regular heats. The alloy cast iron was melted in basic electric furnaces to control composition. The furnace charge was made up of high grade pig iron, foundry scrap, mild steel, coke and alloy additions of manganese, silicon, nickel and molybdenum. Melting practice consisted of melting down, slag removal, oxidizing with iron ore or mill scale, again removing slag, and then superheating to 3000 F. Oxidizing conditions are very important during the superheat. As the melt was tapped, a 1 per cent addition of a nickel alloy inoculant (a 60 per cent nickel, 30 per cent silicon, 10 per cent iron) was added in the preheated ladle.

A portion of the heat was tapped into a shank ladle of 165-lb capacity. The alloy addition, cerium plus any secondary inoculant, was added to the metal as it was tapped. It is necessary to add the cerium before or with a secondary inoculant to obtain the best results.[4] Stirring action of the pouring metal insured proper mixing. Nine cylindrical test bars (1½ by 15 in.) were poured.

The pouring temperatures shown in Table II were measured as the metal was poured into the molds.

* Misch-metal, an alloy containing 45 to 52 per cent cerium, 45 to 48 per cent other rare earths, 0.5 to 2.5 per cent iron, and traces of silicon, aluminum, and calcium.

TABLE III

Chemical Analysis of Melts

Melt	Components, %							
	C	Mn	P	S	Si	Mo	Ni	Ce
A	2.65	1.40	0.024	0.031	2.02	1.01	1.90	0.075
E	2.41	1.57	0.034	0.033	1.96	1.00	1.95	0.027
H	2.69	1.47	0.026	0.026	1.93	1.01	2.64	0.007
I	2.69	1.47	0.026	0.025	1.93	1.01	2.64	0.013
M	2.57	1.74	0.025	0.020	1.75	1.10	1.87	0.035
Q	2.64	1.44	0.036	0.017	1.82	0.96	1.86	0.032
V	2.52	1.35	0.020	0.015	2.53	1.00	1.71	0.035
X	2.52	1.35	0.020	0.017	2.72	1.00	1.71	0.023
IV	2.77	1.33	0.019	0.013	5.87	1.00	2.01	0.026
IW	2.77	1.33	0.019	0.018	3.20	1.00	2.01	0.035
AA	2.47	1.34	0.033	0.017	6.17	1.02	2.27	0.017
BB	2.47	1.34	0.033	0.015	5.92	1.02	2.27	0.018
CC	2.47	1.34	0.033	0.013	4.38	1.02	2.27	0.024
EE	2.47	1.34	0.033	0.018	5.10	1.02	2.27	0.026
FF	2.47	1.34	0.033	0.009	4.85	1.02	2.27	0.018

These temperatures varied, due to exothermic reaction of the secondary inoculants. The molds were made from dry sand cores mounted in one unit and poured from a central downgate. Since the physical properties of the alloy cast iron used vary slightly from heat to heat, an untreated sample was poured for each melt. The effect of the cerium was evaluated by the difference in physical properties of the untreated and the treated samples.

Standard 0.800-in. tensile specimens were machined from the lower portions of the test bars according to ASTM specifications. These were pulled to destruction at a loading factor of 0.4 in. per min. The broken specimens were used for Brinell hardness tests and metallographic examination.

TABLE IV

EXPERIMENTAL RESULTS OF CERIUM ADDITIONS

MELT	ADDITIONS, %				PROPERTIES		STRUCTURE	FIG. No.	REMARKS
	Cerium		Inoculant						
	Added	Retained	Si Source %		Tensile Strength, psi	Hardness, BHN			
A	0.1	0.075	—	—	———	—	White Iron	—	Literature gives 0.1% as upper limit of Ce additions, However, white iron was obtained. There was a pronounced inverse chill.
E	0.04	0.027	—	—	61,800	300	Mottled iron in outside bars, gray iron in center bar. Distinct cast structure with acicular pearlite and carbides in matrix.	1 2	Strength lower than the untreated specimen due to definitely oriented Type E* graphite. Rosette patterns noted, indicating solidification prior to nodule formation. Martensitic regions in Fig. 2 verify rapid chilling. Melt indicates an upper limit of 0.04% Ce under the test conditions.
Untreated	—	—	—	—	67,400	310	Type A Graphite	3	Cast structure is similar to that of Fig. 1.
H	0.01	0.007	—	—	67,200	402	Coarse, well-oriented Graphite structure.	4	Decrease in tensile strength in structure of this kind caused by planes of weakness. Etching** revealed matrix of acicular pearlite and carbides.
I	0.02	0.013	—	—	74,700	407	Imperfect Rosettes	—	Grouping of graphite flakes produced imperfect rosettes similar to type B graphite. Fine matrix shown on etching.
M	0.04	0.035	0.03	Ca Si	———	—	White Iron	—	Amount of silicon added as secondary inoculant was too small.
Q	0.04	0.032	0.04	Ca Si	70,600	321	Gray Iron	—	Graphite structure did not fall into any standard classification. Etching revealed fine, acicular matrix.
V	0.04	0.035	0.3	85% FeSi	73,000	363	Quasi-flakes of graphite—some small nodules.	5	Difficulty in control of the powerful action of calcium silicon led to use of 85% FeSi. Chill areas were visible on etching, indicating lower limit of FeSi additions. Tensile strength was lowered by chill areas.
X	0.04	0.023	0.5	85% FeSi	80,400	310	Similar to V.	—	Chill areas were eliminated, and the size of the carbide areas was reduced.
IW	0.04	0.035	1.0	85% FeSi	76,400	352	Very fine quasi-flakes and nodules.	6	On etching, this melt showed an extremely fine matrix with small areas of carbides.
IV	0.04	0.026	3.0	85% FeSi	20,000	363	Considerable change due to 3% Si addition. True nodules appeared for the first time, surrounded by ferrite areas.	7	Metal was very friable and brittle, making it highly machineable, but of little value because of low tensile strength. Hairline cracks were noted in the ferrite areas. The cause of the cracks is not known, but they were undoubtedly the cause of the brittleness.
AA	0.05	0.017	3.0	85% FeSi	20,000	363	Almost entirely nodular	8 9	Etching revealed structure similar to IV but a new phase, thought to be steadite was noted. The steadite is not explainable, since the phosphorus was very low. Figure 9 contains two graphite nodules surrounded by ferrite, in turn bounded by pearlite. The light mottled area surrounded by pearlite is steadite. Cracks again caused low strength.
BB	0.04	0.018	3.0	85% FeSi	25,000	341	Similar to AA.	10 11	This heat was made to determine reproducibility of results of AA. A similar structure resulted and again, apparently, a new phase (Fig. 10). Fig. 11 shows the skeleton-like structure resembling material described as steadite[3,5] solidifying out of the carbide areas. Why this ingredient presents such a pattern on solidification is not known.
CC	0.04	0.024	1.5	85% FeSi	73,600	375	Fine, unoriented flake graphite mixed with some malformed nodules.	12	Tensile strength very high compared to AA and BB containing nodular graphite. The differences in matrices explains this increase, Fig. 12 showing acicular pearlite surrounding decarburized areas of ferrite.
EE	0.05	0.026	2.0	85% FeSi	33,200	302	Similar to preceding melts.	13	Low tensile strength.
FF	0.04	0.018	2.0	85% FeSi	42,600	341	Similar to EE.	—	There is an interesting comparison between this melt and CC. A variation of 0.5% silicon added in the secondary inoculant resulted in a difference of nearly 100% in tensile strength.

*A.F.S.-ASTM Classification

**All etching using 2% Nital

Unetched 100X

FIGURE 1

2% Nital Etch 100X

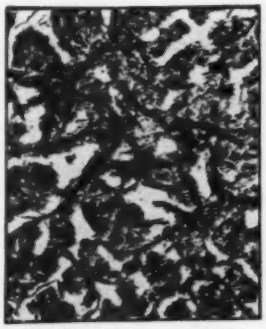
2% Nital Etch 1500X

FIGURE 2

FIGS. 1 AND 2: Melt E; 0.04% Ce added, 0.027% Ce retained. Tensile strength, 61,800 psi; Brinell hardness, 300.

Unetched 100X

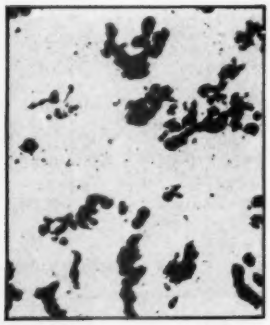
FIGURE 3



2% Nital Etch 100X

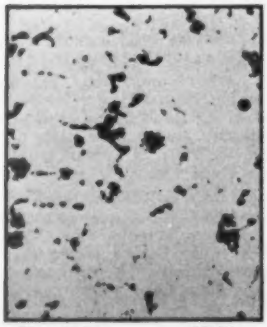
2% Nital Etch 100X

FIGURE 4



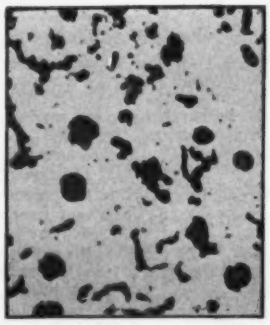
Unetched 100X

FIGURE 5



Unetched 100X

FIGURE 6



Unetched 100X

FIGURE 7

Unetched 100X

2% Nital Etch 100X

FIGURE 8

2% Nital Etch 500X

FIGURE 9

FIG. 3. Untreated cast iron. Tensile strength, 67,400 psi; Brinell hardness, 310.

FIG. 4. Melt H; 0.01% Ce added, 0.007% Ce retained. Tensile strength, 67,200 psi; Brinell hardness, 402.

FIG. 5. Melt V; 0.04% Ce added, 0.035% Ce retained; 0.3% Si added as 85% ferrosilicon. Tensile strength, 73,000 psi; Brinell hardness, 363.

FIG. 6. Melt 1W; 0.04% Ce added, 0.035% Ce retained; 1.0% Si added as 85% ferrosilicon. Tensile strength, 76,400 psi; Brinell hardness, 352.

FIG. 7. Melt 1V; 0.04% Ce added, 0.026% Ce retained; 3% Si added as 85% ferrosilicon. Tensile strength, 31,500 psi; Brinell hardness, 321.

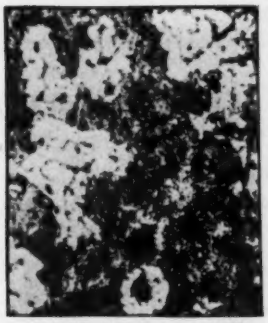
FIGS. 8 AND 9. Melt AA; 0.05% Ce added, 0.017% Ce retained; 3% Si added as 85% ferrosilicon. Tensile strength, 20,000 psi; Brinell hardness, 363.

Unetched 100X

FIGURE 10

2% Nital Etch 500X

FIGURE 11



2% Nital Etch 100X

FIGURE 12

2% Nital Etch 100X

FIGURE 13

FIGS. 10 AND 11. Melt BB; 0.04% Ce added, 0.018% Ce retained; 3% Si added as 85% ferrosilicon. Tensile strength, 25,000 psi; Brinell hardness, 341.

FIG. 12. Melt CC; 0.04% Ce added; 0.024% Ce retained; 1.5% Si added as 85% ferrosilicon. Tensile strength, 73,600 psi; Brinell hardness, 375.

FIG. 13. Melt EE; 0.05% Ce added, 0.026% Ce retained; 2% Si added as ferrosilicon. Tensile strength, 33,200 psi; Brinell hardness, 302.

Drill shavings were taken from the test bars for analysis (Table III). Because of the small percentages of cerium, colorimetric determinations were run. This determination consists of dissolving a standard sample in hydrochloric acid, oxidizing the solution, adjusting the pH, electrolytically removing the iron, manganese, nickel and molybdenum, reducing the cerium, re-adjusting the pH, and extracting the cerium with a reagent of 8-hydroxyquinoline dissolved in chloroform.

The absorption of the cerium-8-hydroxyquinoline solution when using a green filter (540 millimicrons) is measured in a Klett photometer and the percentage of cerium read from a calibration graph. Full details of the method are given by Westwood and Mayer.[6]

Standard determinations were run for the other elements.

The first series of tests were made to investigate the effect of various cerium additions on the physical properties of the alloy cast iron. The second series investigated the effects of cerium plus a secondary inoculant. The results of these experiments are presented in Table IV.

Summary

Cerium affected the graphite structure in all melts. Cerium alone tended to produce oriented graphite of Type E, which lowered the tensile strength. A pronounced chilling effect was noted in melts treated with cerium alone. Desulphurization was not completed to the extent reported by Morrogh and Williams.[4]

The addition of a secondary inoculant with the cerium improved the tensile strength and graphite structure. Both the type and amount of the secondary inoculant influenced the amount of acicular pearlite produced. In the alloy cast iron the maximum tensile strength is associated with the amount of acicular pearlite and the size of Type A graphite.

Nodular graphite structures were obtained in the alloy cast iron, but at the expense of modifying the acicular pearlite matrix.

The most desirable physical properties were obtained in the range of 0.04 to 0.05 per cent cerium with 1.0 to 1.2 per cent silicon added by ferrosilicon as a secondary inoculant.

ACKNOWLEDGMENTS

The authors are indebted to the Pacific Car and Foundry Co. and to Dr. Alexander Finlayson, technical director, and Herbert A. Conyne, metallurgist, for use of foundry facilities, and assistance in the conduction of the investigation. Grateful acknowledgment is made to the Engineering Experiment Station, University of Washington, sponsor of the project.

REFERENCES

1. *Metals Handbook,* 1948 edition, American Society for Metals, Cleveland.
2. HEYER, R. H., *Engineering Physical Metallurgy,* D. Van Nostrand & Co., New York, 1939.
3. LOWNIE, H. W., JR., "Theories of Gray Cast Iron Inoculation," *Transactions,* American Foundrymen's Society, Vol. 45, p. 837 (1946).
4. MORROGH, H., and WILLIAMS, W. J., "The Production of Nodular Graphite Structures in Cast Iron," *Journal of the Iron and Steel Institute,* March, 1948, pp. 306-322.
5. ROSENHAIN, W., *Introduction to Physical Metallurgy,* p. 310, D. Van Nostrand & Co., 1914.
6. WESTWOOD, W., and MAYER, A., "The Determination of Cerium in Cast Iron," *Analyst,* May, 1948, Vol. 73, No. 866, pp. 275-282.

THE CHLORINATION OF OLIVINE ORE*

H. H. GREENFIELD
Research Fellow, Engineering Experiment Station

R. W. MOULTON
Professor of Chemical Engineering

H. H. Greenfield

Introduction

As a part of its program of contributing to the development of natural resources of the region, the Engineering Experiment Station became interested in the olivine deposits of the state of Washington as a source of metallic magnesium because of their magnitude and also their proximity to hydroelectric power.

Research on the magnesium-from-olivine process, originally intended for peacetime use, was given impetus by the shortage of magnesium that existed at the beginning of World War II. However, the shortage has been met by expansion and development of other processes,[1, 2, 3] before this process was sufficiently developed to justify its inclusion in the war program. It is believed that the magnesium-from-olivine process may have advantages that will make it feasible to compete with other existing processes.

Previous Work on Olivine

The work done on olivine to date has been along three general lines of investigation:

1. Acid leaching of the ore[4]
2. Dry chlorination of the ore using chlorine gas or hydrogen chloride gas[5, 6, 7, 8]
3. The direct reduction of the ore using carbon or calcium carbide[9, 10]

The chlorination of olivine ore, carried out by many investigators on pilot-plant and semi-pilot-plant scales, has left many questions still unanswered as to the reaction kinetics involved. It was believed that further investigation on a laboratory scale, controlling the chlorinating conditions and increasing the accuracy of the measurements of gas flow and temperature would provide us with better understanding of the reaction kinetics involved, and thus lead to better pilot-plant design. It was also decided to carry out chlorination at a temperature above the boiling point of magnesium chloride, since the work of the previous investigators indicate that a greater yield of anhydrous magnesium chloride is obtained at higher temperatures.

R. W. Moulton

Equipment

Furnace. With the decision to carry out chlorination at a temperature above the boiling point of magnesium chloride, a molybdenum resistance wire tube furnace was designed on the consideration of temperature and resistance to chemical action of chlorine gas. The resistance wire furnace is also easy in temperature control and has no secondary effects such as ore action. On the basis of heat balance and using a reasonable factor of safety, a 4-kw power supply to the furnace was selected, and the furnace was constructed according to the general directions of the Fansteel Metallurgical Corporation.[11] A round smooth refractory tube 18 in. in length, manufactured from the Norton Company's alundum mixture R.A.-1139, was used. The tube has an inside diameter of 3 in. and a wall thickness of 0.375 in.

From the consideration of the size of the tube to be used and the maximum current allowable in the laboratory, 100 ft of 0.050-in. molybdenum wire was selected for the tube winding. This wire was wound 6.5 turns to the inch over 16 in. of the tube length. After the tube was wound with wire, it was plastered with Norton Company's R.A.-1148 cement to the depth of 0.25 in. and then was air dried.

The housing of the furnace tube consisted of an 18-in. long steel tube obtained from a 12-in. standard steel pipe which was mounted horizontally on a welded steel stand. Two suitable end plates accommodating the gas supply distribution pipe and a quartz window were used. About 200 lb of finely ground zirconium oxide was used as an insulation between the housing tube and the alundum refractory tube.

Though hydrogen, dissociated (cracked) anhydrous ammonia, or "forming gas" may be used as an

* Condensed by N. R. Mukherjee, from the M.S. thesis in Chemical Engineering submitted by H. H. Greenfield, 1948.

inert gas for the protection of molybdenum winding from oxidation, commercial nitrogen was used in this furnace because of its cheapness and availability. It was necessary to remove the oxygen and water from this commercial variety of nitrogen gas.

The temperature of the furnace was controlled by controlling the voltage by means of 110-v variac with the cage rheostat. The temperature was measured by a calibrated optical pyrometer manufactured by the Leeds & Northrup Company.

Reaction Chamber. In order to carry on the chlorination reaction at the proposed temperature it was necessary to resort to the use of graphite in all parts of the apparatus with which chlorine came in contact, in order to prevent undue contamination to the reactants and products. Graphite obtained in the form of graphite electrodes, 2.5 in. in diameter, was used to construct the reaction chamber and the chlorine gas line in the preheater and furnace, as well as the magnesium chloride condenser.

Preheater. The preheater was made from two half sections of 3-in. diameter nichrome wire furnace coil heaters held together by a layer of asbestos paper and asbestos ribbon. The graphite tubing was put inside the furnace. A temperature of 700° C on the surface of the graphite pipe was maintained, and the temperature was measured by iron-constantan thermocouple.

Exit Gas Heater. The purpose of this heater was to maintain the temperature in the inlet pipe of the condenser above the melting point of magnesium chloride so that the pipe would not become plugged with solids.

Magnesium Chloride Condenser. The magnesium chloride condenser was made from a 3-liter jar, provided with connections for the inlet gases and the non-condensable gases leaving. The pipe fittings were made from black iron, which was found to be more resistant to corrosion than stainless steel.

Flow Meters. Orifice-type glass flow meters were made by inserting a capillary glass tubing in the gas line with two pressure tops at the upstream and downstream connected by a glass U tube. The U tube was filled with water for nitrogen flow, with mercury for helium flow and with concentrated sulphuric acid (sp gr 1.8) for chlorine flow. All of the orifice-type meters were calibrated against a standard gas meter. An iron-orifice flow meter was used to measure, qualitatively, the flow of the noncondensable gases from the magnesium chloride condenser.

Thermodynamic Consideration

In order to study the reaction equilibrium, effects of side reactions, and the temperature effects on equilibrium, the change in free energy was determined as a function of temperature for the reaction,

$$Mg_2SiO_{4(solid)} + 2C_{(solid)} + 2Cl_{2(gas)} = MgCl_{2(liquid)} + SiO_{2(solid)} + 2\,CO_{(gas)} \cdot \qquad (1)$$

From the data given by Kelly,[12] Oliver,[7] the following equation for free energy was obtained:

$$\Delta F^\circ = -88{,}360 - 25.1\,T \log T + 1.58\times10^{-3}\,T^2 - 4.17\times10^{5}\,T^{-1} + 38.3\,T\,, \qquad (2)$$

where T is the absolute temperature.

From this equation the values in Table I were calculated, and the curve $1/T$ versus log K (equilibrium constant) was found to be linear.

The values of the equilibrium constant show that the reaction is complete for all temperatures below the boiling point of magnesium chloride.

TABLE I

Temperature T° Kelvin	$\frac{1}{T}$	Free Energy F° (K Cal)	Equilibrium Constant K	Log K
1000	0.00100	−124.2	1.58×10^{27}	27.2
1300	0.00077	−137.7	1.41×10^{23}	23.15
1690	0.00059	−156.3	1.78×10^{20}	20.25

Experimental Procedure

Two chlorination runs were made using ore from the Twin Sisters deposits.

Run No. 1. The olivine ore was screened and dried at 150° C and 10.6 g of –65 to –100-mesh ore was used for the run. The carbon used was turnings and powder from the machinery of the graphite electrodes. The graphite was screened and iron particles were removed with a magnet. The particle size of graphite was also in the range –65 and –100 mesh. The mixture consisted of 59 per cent olivine and 41 per cent carbon by weight, which is equivalent to over 3.5 times the stoichiometric carbon requirement.

The olivine and carbon, mixed thoroughly, were poured into the reaction chamber and the accessories were arranged properly. Then the furnace was brought up slowly to the desired chlorinating temperature of 1590° C over a period of twelve hours. Chlorine was then admitted at a rate of 150 c.c. per minute for 17 minutes and then at 60 c.c. per minute for 8 minutes. Helium was also admitted at a rate of 72 c.c. per minute over the 25-minute period of chlorination. Dense white clouds of magnesium chloride were observed settling in the condenser jar less than one minute after the chlorine was admitted. The non-

TABLE II

Run No.	Temp. °C.	Time Min.	Reaction Mixture in grams		Ratio Olivine/ Carbon	Olivine Mesh Size	Chlorine flow rate		Conversion % Mg	Magnesium Found in Condenser (% Mg Reacted)	Residue Analysis (less carbon content)		
			Olivine	Carbon			c.c. per min	gms. per min			SiO_2	MgO	R_2O_3
1	1591 to 1677	17	10.60	7.37	1.44	−65 to +100	150	0.437	43.0	95	49.4	36.5	14.1
	1591 to 1677	8					60	0.175					
2	1429 to 1507	70	11.72	6.81	1.72	−100 to +150	37	0.108	45.8	96	51.8	34.6	13.6
	1416	10					56	0.163					
	1423 to 1486	20					35	0.102					
	1289 to 1328	14					53	0.154					
	1289 to 1328	6					39	0.114					

condensable gases were either absorbed in the solutions of sodium hydroxide and cuprous ammonium chloride or were drawn off by the water aspirator. At the end of thirty minutes of chlorination, the static pressure in the reaction chamber and alundum tube had built up to the point where it was necessary to stop the chlorination. On examination of the different parts of the apparatus it was found that the gas containing magnesium chloride leaked through the cover plate, and the bottom of the condenser jar was covered with a layer of fine white anhydrous magnesium chloride particles. Other minor troubles were also checked.

On analysis according to procedure outlined by Kolthoff and Sandell,[12] the run showed that 43 per cent of the magnesium present in the olivine was converted to anhydrous magnesium chloride.

Run No. 2. In this run, the defects of the apparatus detected in Run No. 1 were corrected. In other respects the run was made almost in the same way as the previous one, as shown in Table II.

Discussion

The results of the two chlorination runs are pretty much in agreement with what one would expect in the light of the reaction mechanism, which has been discussed in detail in the original thesis. The factors, which govern the reaction mechanism, are (1) the condition of the material in the reaction zone, (2) the temperature at which the reaction is carried out, and (3) the state of the products when removed from the reaction zone. The selection of the temperature at which the reaction is carried out will determine the state of the products when removed from the reaction zone. The condition of the material in the reaction zone includes the particle size, state of aggregation, and agglomeration of the solid charge-materials. In the first run 96 per cent of the required chlorine was used, but an excess of 40 per cent chlorine was used on the second run based on the complete chlorination of the magnesium present in the olivine ore. The mesh size and the total time of chlorination were, in effect, the only differences in the two chlorinating runs. Of these two factors, the mesh size was found by previous workers[3, 7] to be far more important. The conversion of magnesium oxide to a greater degree in the second run was expected due to the smaller particles of the ore. (See Table II.)

It was found that the iron in the olivine was not chlorinated. The iron in the residue was in the form of ferrosilicon. This could readily be separated from the rest of the residue by use of a magnet. Hansgirg[9] pointed out that the silica is reduced to silicon at temperatures around 1600° C by carbon and the silicon alloys with iron of the ore forming ferrosilicon. In

(Continued on page 28)

Engineering Research Dividends

Recent theses submitted for advanced degrees from the College of Engineering, University of Washington, will regularly appear in abstract form in *The Trend*. Complete copies of these theses are available for reference at the University of Washington Library. Address inquiries to the Director of the Engineering Experiment Station, University of Washington, Seattle 5.

RUSSELL, G. M., "Microwave Mirrors." M.S. in Electrical Engineering, 1951.

This paper reports an attempt to verify a theoretical prediction of flat-reflector performance proposed by R. W. Ehrlich. Measurements were made at a frequency of 10,000 mc of the energy reflected from aluminum mirrors one, two and four feet in diameter to antennas of two typical forms. It was found that the variation of received signals with spacing between reflector and antenna followed the general shape of the predicted curves but with as much as 9 db less received power. It is concluded that in practical applications this theory will be useful for estimating performance and selecting the optimum size of mirror. However, the predicted signal strength will probably be unobtainable. The effect of apparent distortion of reflector shape due to parallax was investigated and found to be negligible in the proportions of a practical system. Also, the performance of a microwave mirror appears to be independent of the polarity of the incident waves.

SMITH, R. H., "Limitations of Large Turning Angle Cascades of Airfoils for Flow Diffusion." M.S. in Aeronautical Engineering, 1952.

Space limitations frequently interfere with use of the familiar gradually expanding duct for stream diffusion in internal flow systems. Since such space limitations usually occur along with a necessity for deflection of the flow around a corner, the possibility of simultaneous diffusion and deflection of the stream is of interest. The use in this way of small turning angle cascades of airfoils (or their equivalent) is well known in the case of axial flow fans. In order to provide a basis for reckoning the merit of large turning angle cascades of airfoils for incompressible flow diffusion, an analysis of such cascades was conducted for conditions approximating the limits of performance without excessive losses. The occurrence of separation or flow reversal on the airfoil surfaces defines the advent of excessive losses; accordingly means for predicting this phenomenon were incorporated in the analysis where they form the basis for distinguishing between acceptable and unacceptable cascade performance. The minimum cascade solidity (ratio of blade chord to blade spacing) required under these conditions was found in terms of turning angle and the ratio of velocities, upstream to downstream. These results indicate that velocity ratios exceeding 1.5 should not be considered for use with turning angles over 45 degrees because solidities greater than 3.0 would be required to prevent excessive losses. Velocity ratios of 1.5 or less may be successfully employed with turning angles up to 90 degrees and possibly beyond, provided a carefully designed cascade is used.

McKEE, R. B., "The Design and Construction of a Small Free-Piston Compressor." M.S. in Mechanical Engineering, 1951.

As a means of compressing gaseous media, a free-piston design presents the advantages of extreme light weight and vibrationless, high-speed action when compared with the conventional piston, connecting rod and crank type compressor. In the University of Washington Mechanical Engineering Laboratory, a single cylinder, free-piston air compressor is being built which, it is expected, will deliver approximately 25 cfm free air at 90-psia discharge pressure. The power head uses a spark-ignited Otto cycle with gasoline as a fuel. The three intake valves are of the poppet type; the exhaust valves are ports. The fuel mixture enters the cylinder above atmospheric pressure in order to scavenge the burnt gases. At present, this supercharging effect is accomplished by means of an independently supplied source of compressed air, but in the future, it will be done by a bleeder line from the unit's receiving tank. The piston and cylinder walls are lubricated by means of a drop-feed oiling system. Cooling is accomplished with a water jacket. It is hoped that effective carburetion is the only problem left. When it is solved, test runs on the compressor will be made.

TIEDEMANN, J. L., "Lateral Buckling of Simply-Supported Rolled Steel Beams." M.S. in Civil Engineering, 1951.

The primary purpose of this investigation was to compare the buckling strengths of actual test beams

(Continued on page 28)

Engineering College Professors Retire After Long Service

Four professors in the College of Engineering retired from teaching at the end of June. Dean Emeritus Edgar A. Loew and Professor Gordon R. Shuck of the Department of Electrical Engineering, and Professor Arthur M. Winslow of the Department of Mechanical Engineering have reached the age limit established by the Board of Regents. Professor Amy V. Hall of the Department of Humanistic-Social Studies was granted permission to retire at her request. The four have a combined record of distinguished service to the University totaling 139 years.

Edgar Allan Loew

Professor Loew received the degree of B.S. in E.E. from the University of Wisconsin in 1906 and the Electrical Engineer degree from the same University in 1922. He became an instructor in electrical engineering at the University of Washington in 1909 and was promoted to the rank of full professor in 1923 and to Dean of the College of Engineering in 1935. These positions he held until 1948 when he retired from administrative work, continuing as Professor of Electrical Engineering and Dean Emeritus.

He has been very active in the American Institute of Electrical Engineers, an Associate in 1908 and a Fellow in 1936, and served as secretary of the Seattle Section 1913-1915 and as chairman in 1925 and 1926. He has also been very active in the ASEE and the ECPD. He has a long list of publications in such outstanding periodicals as the AIEE, and has had two books published by the McGraw-Hill Book Company. The first, *Electrical Power Transmission,* published in 1928, is recognized as an authority in its field. The second is *Direct and Alternating Currents,* now being revised for its fourth edition.

Gordon Russell Shuck

Professor Shuck received his engineering education at the University of Minnesota, where he was awarded the degree of Electrical Engineering in 1906. In 1918 he came to the University of Washington as an instructor in electrical engineering and rose through the professional ranks to the grade of professor in 1937. He is a member of the AIEE and was chairman of the Seattle Section in 1940. He was also chairman of the Washington State Chapter of the Illuminating Engineering Society in 1947. He has a number of patents on electric meters and has published a number of metering papers in *Electrical Engineering* and other engineering publications.

Arthur M. Winslow

Professor Winslow earned his Ph.D. degree in mathematics at Brown University in 1903 and his B.S. at M.I.T. in 1906. He joined the Mechanical Engineering staff at the University of Washington in 1918, where he has held the rank of professor since 1927. His greatest interests and contributions have been in machine design, vibrations, and power plants. His research has been largely in the field of stress analysis and elastic theory. Outstanding in his early research was an investigation, with Professor R. H. G. Edmonds, of the theory of curved beams with strain gage and photoelastic experimental check. In July, 1934, he presented in person a paper on "Study of Fundamental Relations of the Mathematical Theory of Elasticity," at the fourth International Congress of Applied Mechanics in Cambridge, England.

In recent years, he has made notable additions to the literature through extension and simplification of the application of Fourier series to problems of elasticity, the most recent publication being "Differentiation of Fourier Series in Stress Solutions for Rectangular Plates" in the *Quarterly Journal of Mechanics and Applied Mathematics.*

Amy Violet Hall

Professor Hall received her B.Ed. in 1920, her M.A. degree in 1923, and her Ph.D. in 1940, all from the University of Washington. She became an instructor in the English Department in 1924 and was promoted to a full professorship in 1949. Her broad background and keen intellectual curiosity made her especially fitted for what soon became her life work—teaching engineering students how to communicate their ideas and to cultivate an acquaintance with the humanities.

In 1947 when her work evolved into the Department of Humanistic-Social Studies of the College of Engineering, Professor Hall was Acting Executive Officer for the first two critical years of organization and curricular development.

The present departmental library grew out of her gift of several thousand volumes from her personal library. At the June meeting of the ASEE held at Dartmouth College, Dr. Hall was the guest of honor at the Annual Joint Dinner of the English and Humanities Sections, speaking on, "A Beginning Synthesis: the Sciences and the Humanities."

CITY AIR-POLLUTION REPORT RELEASED

(Continued from page 7)

odors from Tacoma and Everett as the wind is in the south or north. Obviously, therefore, the air-pollution problem should be attacked in all of these communities if it is to be satisfactorily controlled.

The dustfall remains unusually constant throughout the year, with the heaviest fall shifting southward under the northerly winds of summer, and returning northward with the winter's southerly winds. The filter disks which are darkened more by the carbon in smoke than by its dust content, are distinctly darker in winter than in summer.

The Seattle and Los Angeles meteorological characteristics which account for their worst smog conditions are quite similar in that each has frequent atmospheric inversions. A common type of inversion occurs when ground cooling chills the lower air layers to a temperature below that at a higher level. Since the cold air is heavier it remains below the warmer air and does not mix with it. Thus it and its burden of smoke, etc., envelopes the city and continues to increase in concentration for as long as the inversion lasts. Such inversions, with their pollutants concentrated during several days without the usual dissipation to the upper atmosphere, took 20 lives at Donora, Pensylvania, in October, 1948, while 5,910 were affected. In the Meuse River Valley in Belgium in December, 1931, 63 people lost their lives, and thousands were affected.

During the year covered by the Seattle study, there were many inversions, two of which continued for five or six days. During such periods the haze becomes dense and the visibility is greatly decreased. They are readily recognized by an early morning low-lying, dark cloud bank over parts of the City. These may be dissipated within an hour or two as the sun heats the ground and its adjacent air and thus forms convection currents which may cause sufficient mixing to dissipate the upper layer of warm air causing the inversion.

An illustrative example of an inversion (Fig. 1) shows a thin strip of land above the smog and at the level of the bottom of the warm air layer which kept the clouds from rising and the smoke from being dissipated. The top of the smog layer is at the approximate elevation of the inversion as indicated by radiosonde data from the Sand Point Naval Station. I suggest that Seattle citizens watch the smog conditions which usually cover the City only in part so that one hill may have a haze covering while another may be quite clear. This haze is caused, in many cases, by the inversion condition herein discussed which forms an effective lid for keeping the air pollutants confined in the lower air layer. Oil sleeks have been studied by the harbor patrol for which the only apparent cause has been the contact of the water with low-lying smog blankets. That on Lake Washington on March 27-28, 1952, was apparently caused in this way.

Fortunately, the causes of much of the local smoke can be remedied. Residential smoke from oil burners can be eliminated by cleaning and adjusting the the burners. As mentioned in the report, there is some evidence of down-grading of fuel oils as more of the lighter fractions are being removed at the refinery. More air is required to burn these oils without smoke. Coal burners account for much of the residential smoke since locally burned coals have a high volatile content which makes smokeless burning difficult. But here also smoke can be held to acceptable standards.

Much of the industrial smoke comes from the burning of wood wastes or what is usually called hogged fuel. This material is made up of miscellaneous wastes fom lumber mills and wood-working industries and includes pieces of board, shavings, saw dust, sander dust, etc. from the different kinds of timber grown in this area. These contain varying amounts of moisture, a great range of size, and are often mixed with no uniformity. To try to feed a furnace uniformly with such fuels so as to provide constant conditions for burning is obviously impossible. Also, since these differences in moisture content and in size and character of wood demand differences in the air supply, temperature of burning, etc., the use of varying admixtures of these various elements makes it impossible to burn the wastes completely and with the best air-fuel ratios. Furthermore, the fuel is relatively inexpensive so proper methods for ventilation and combustion are not provided. It is not surprising therefore that hogged fuel causes so much of the total smoke produced in Seattle. Adequate grading, drying, and uniform feeding of this fuel would do much toward reducing the smoke now being produced through its use. Over-fire air jets in the Dutch ovens employed would do much to effect satisfactory combustion.

The development of a use for these wastes as in the manufacture of some of the soft- or hard-wood products that can be made from them would go far toward eliminating the smoke they at present produce. In the meantime, better draft regulation and uniform feeding of the graded and dried fuel is capable of meeting the usual requirements for allowable smoke emission.

Fortunately, Seattle does not have toxic materials such as fluorides in its atmosphere. A very thorough

test series resulted in this conclusion. Other gases such as SO_2, CO_2, etc. are present as in all cities. The former under some conditions produces sulfuric acid which corrodes steel structures and attacks stone and concrete. It should therefore be kept to a minimum.

The Seattle Air Pollution Report concludes with the following recommendations:

1. That an Air Pollution Control ordinance be set up by the City of Seattle defining air pollution, establishing a Division of Air Pollution Control in an appropriate City Department, and outlining its duties and responsibilities.

2. That a study of all smoke, fumes, or dust-producing plants in the city should be made by the Division of Air Pollution Control and these plants should be notified of the manner and extent of their failure to comply with the requirements of said ordinance. Said plants may seek the advice of experts in this field, of which there are an ample supply in Seattle.

3. That a city-wide educational program be set up such as discussed above, in which the widest possible cooperation should be secured and adequate expert leadership provided for informing the people and plant management throughout the city concerning the air pollution existing in Seattle together with its significance, cost to the community, and methods for its reduction.

CHLORINATION OF OLIVINE ORE

(Continued from page 24)

the first run approximately 90 per cent of the iron in the original ore was found in the residue, and 100 per cent of iron of the original ore was found in the residue of the second run.

Summary

1. A molybdenum wire resistance tube furnace and necessary auxiliary apparatus were designed, built and operated to study quantitively the chlorination of olivine ore at high temperatures.

2. It was shown on a laboratory scale, that from 43 to 46 per cent of the magnesium content of the olivine ore can be converted to anhydrous magnesium chloride at temperatures above the boiling point of magnesium chloride and separated from the other materials of the olivine ore.

3. The results of the chlorination runs showed that 95 to 96 per cent of the magnesium chloride was volatilized out of the reaction chamber.

4. Decreasing the particle size resulted in a higher percentage of magnesium converted, since the reaction took place on the surface of the particles.

5. None of the iron content of the olivine ore was chlorinated.

6. Some of the silica was reduced at these high temperatures by carbon to form silicon, which alloyed with the iron content of the ore to form ferrosilicon. The ferrosilicon was readily separated from the residue by magnet.

7. It appeared that the amount of silica (4 to 13 per cent) unaccounted for by the silicon balance was chlorinated to form the volatile silicon tetrachloride.

8. The unreacted chlorine and carbon monoxide formed phosgene gas at temperatures less than 400° C and thus accounted for the large losses of chlorine reported by other investigators.

REFERENCES

1. Melndoe, W. C., *Chem. Ind.* **49**, 162 (1941).
2. Wilson, P. D., *Min. and Met.* **23**, 201 (1942).
3. Pidgeon, L. M., *Canadian Inst. Min. and Met.* **47**, 16 (1944).
4. Powel, G. W., *Min. and Met.*, **23**, 331 (1942).
5. Hansen, W. W., Thesis, Washington State College, 1944.
6. Ebright, D. P., Thesis, University of Washington, 1947.
7. Oliver, E. D., Thesis, University of Washington, 1947.
8. Brooks, R. J., Thesis, University of Washington, 1946.
9. Hansgirg, F. J., U.S. Patent 2,372,571, March 27, 1945.
10. Hybinette, S. E., and Cary, F. C., U.S. Patent 2,396,658, March 19, 1946.
11. "Construction and Operation of Molybdenum Wound Furnace," Pamphlet, Fanstell Metallurgical Corporation, North Chicago, Ill.
12. Kolthoff, I. M., and Sandell, E. B., *Textbook of Quantitative Inorganic Analysis*, New York, MacMillan Company, 1942, pp. 697-710.

TIEDEMANN: LATERAL BUCKLING OF BEAMS

(Continued from page 25)

with the values predicted by the AISC formula for the buckling strength of uniformly loaded beams. Twenty-seven lateral buckling tests were made on the following three rolled sections, all of which had nearly the same d/bt ratio: 18WF50, 12WF27 and 10I25.4. Duplicate beams of each section were tested on spans of 120, 150, 240, and 360 inches, and an additional three tests of the 18WF50 beams on a 600-inch span were made. For the beams on the longer spans, the buckling strengths compare quite favorably with the predictions of the AISC formula for buckling, while the buckling strength of the shorter beams was somewhat less than the values predicted by this formula. These longer beams had a proportionately larger amount of lateral deflection prior to buckling than did the shorter beams. Initial out-of-alignment of the flanges had a greater influence on the buckling strength of the slender beams than it did on the short beams. The bending stiffness in the weak direction and the torsional stiffness were controlling factors in the buckling of slender beams. The bending stiffness in the strong direction was the more important factor in the short beams.

PUBLICATIONS

of the

ENGINEERING EXPERIMENT STATION

UNIVERSITY OF WASHINGTON

Requests for copies of publications should be addressed to the Director, Engineering Experiment Station, University of Washington, Seattle 5.

BULLETINS

48. The Influence of Pipe Thickness on Re-Entrant Intake Losses. Charles William Harris. 35 pp. 1928.
56. Constant Flow Characteristic of the Plane Orifice in Proximity to Side Walls. Charles William Harris. 18 pp. 1931.
58. Preliminary Tests of Thirteen Washington Coals in a Powdered Coal Boiler Plant at the University of Washington. George Samuel Wilson, Harry Fagan Yancey, and Joseph Daniels. 27 pp. 1931.
60. An Electromagnetic Balance for Force Measurement of Current Control. Fred Scoville Eastman, 29 pp. 1932.
61. Hydraulic Flow Characteristics of a Square-Edged Intake. Charles William Harris. 21 pp. 1932.
67. The Doherty Washer Cooler. Sybren Ruurd Tymstra. 61 pp. 1932.
72. The Derivation of the Mean Temperature Difference Between a Saturated Gas and a Cooling Liquid, and also the Derivation of the Mean Velocity of Such Gas. Sybren Ruurd Tymstra. 19 pp. 1933.
74. The Deformation of Hard Grade Reinforcing Steel During and After Construction in a Reinforced Concrete Building. Sergius Ivan Sergev. 33 pp. 1933.
75. The Water Tube Gas Condenser. Sybren Ruurd Tymstra. 24 pp. 1934.
76. Kaolin and China Clay in the Pacific Northwest. Hewitt Wilson. 184 pp. 1934.
77. A Study of Fundamental Relations of the Mathematical Theory of Elasticity. Arthur Melvin Winslow. 25 pp. 1934.
78. Hydroelectric Power in Washington. Part III, A Brief on Proposed Grand Coulee Dams. Carl Edward Magnusson. 32 pp. 1935.
79. Cycloidal Propulsion in Air. Part I, Cycloidal Propulsion Theory; Part II, Cycloidal Propeller Development at the University of Washington. Frederick Kurt Kirsten. 87 pp. 1935.
81. Influence of Two Secondary Factors in Weir Measurement. Charles William Harris. 16 pp. 1935.
84. Equations for Calculating Three Phase Symmetrical Components. Gordon Russell Shuck. 32 pp. 1935.
85. Discharge of Three Commercial Cippoletti Weirs. Robert Bowman Van Horn. 32 pp. 1935.
86. Flexure Pivots to Replace Knife Edges and Ball Bearings. Fred Scoville Eastman. 47 pp. 1935.
87. Open Water Testing of Ship Models. Thomas McKie Rowlands. 20 pp. 1935.
88. The Properties of Quartz Sands Washed from Kaolins of the Pacific Northwest. Hewitt Wilson and Frank Joseph Zvanut. 42 pp. 1936.
90. Hydroelectric Power in Washington. Part IV, Regional Electric Power Transmission. The Grid System. Carl Edward Magnusson. 51 pp. 1936.
91. The Analysis and Control of Landslides. Robert Graham Hennes. 57 pp. 1936.
92. Moment Equations. A Method of Analysis for Continuous Beams and Rigid Frames. Alfred Jensen. 88 pp. 1937.
93. Electric Power Markets in Washington. Part I, Electric Heating of Residences. Carl Edward Magnusson. 40 pp. 1937.
94. Evaporative and Surface Cooling. George Samuel Wilson and William Lyle Dudley. 18 pp. 1937.
95. Hydroelectric Power in Washington. Part V, A Bibliography of Technical Papers, 1926-1935. Carl Edward Magnusson. 204 pp. 1937.
96. Hydroelectric Power in Washington. Part VI, International Boundary Waters. Carl Edward Magnusson. 17 pp. 1937.
97. Strength of Concrete for Mixes of Various Proportions. Ira Leonard Collier. 28 pp. 1938.
98. Geology and Its Relation to the Occurrence of Oil in Washington. Charles Edwin Weaver. 16 pp. 1938.
99. Electric Power Markets in Washington. Part II, Residence Service Markets and a Regional Power Grid. Carl Edward Magnusson. 92 pp. 1938.
100. Modernization of a Transit System. Factors that Determine the Choice of a Vehicle. George Lisle Hoard. 36 pp. 1940.
101. Buckling Criteria and Design of Two-Story Columns. Sergius I. Sergev. 48 pp. 1940.
102. An Investigation of Prestressed Stays. T. M. Rowlands and F. C. Smith. 36 pp. 1941.
103. Bismuth Bridge Magnetic Flux Meter. George Sherman Smith. 48 pp. 1940.
104. The Telechronometer, Telephone Service Measurement in Units of Time. Lyall Baker Cochran. 68 pp. 1941.
105. Theory of Flexure of Structural Members of Non-uniform Section Alfred L. Miller. 68 pp. 1940.
106. The Shearing Strength of Cement Mortar. Frederick C. Smith and Robert Q. Brown. 32 pp. 1941.
107. A Geologic Interpretation of the Failure of the Cedar Reservoir, Washington. J. Hoover Mackin. 30 pp. 1941.
108. Silica Sands of Washington. Hewitt Wilson, Kenneth G. Skinner and Albert H. Couch. 76 pp. 1942.
109. The Number of Teeth in Contact as a Vibration Factor in Involute Cut Gears. Sybren Ruurd Tymstra. 16 pp. 1942.
110. Solutions for Torsional Vibration Frequencies by Energy Method. Arthur Melvin Winslow. 22 pp. 1943.
111. Stabilized Earth Blocks for Protective Construction. Robert G. Hennes. 24 pp. 1943.
112. Hydraulic Models. Charles W. Harris. 17 pp. 1944.
113. The Theoretical Behavior and Design of Initially Curved Struts Under an Intermediate Concentric Axial Load. Sergius I. Sergev. 32 pp. 1945.
114. The Effect of Shearing Forces on the Deflection and Strength of Beams. Sergius I. Sergev. 20 pp. 1947.
115. The Influence of Random Roughness on Flow in Pipes. Charles W. Harris. 19 pp. 1949.
116. Aerodynamic Stability of Suspension Bridges with Special Reference to the Tacoma Narrows Bridge. Part I, Investigations Prior to October, 1941. F. B. Farquharson. 103 pp. 1949.

116. Aerodynamic Stability of Suspension Bridges with Special Reference to the Tacoma Narrows Bridge. Part II, Mathematical Analyses. F. C. Smith and G. S. Vincent. 63 pp. 1950.

116. Aerodynamic Stability of Suspension Bridges with Special Reference to the Tacoma Narrows Bridge. Part III, The Investigation of Models of the Original Tacoma Narrows Bridge Under the Action of Wind. F. B. Farquharson. 125 pp. 1952.

116. Aerodynamic Stability of Suspension Bridges with Special Reference to the Tacoma Narrows Bridge. Part IV, The Investigation of Models of the New Tacoma Narrows Bridge Under the Action of Wind. F. B. Farquharson. (In preparation.)

116. Aerodynamic Stability of Suspension Bridges with Special Reference to the Tacoma Narrows Bridge. Part V, Amplitude Predictions, Damping Tests, and General Investigations of Suspension Bridges. G. S. Vincent. (In preparation.)

117. Production of Wood Coke from Waste Wood. Warren L. Beuschlein. 40 pp. 1950.
118. Investigations in Aeronautics from the Department of Aeronautical Engineering. Edited by R. M. Rosenberg. 120 pp. 1951. Price: Two dollars.
119. The Extremum Principles of the Mathematical Theory of Elasticity and Their Use in Stress Analysis. (The Walker-Ames lectures of the Spring Quarter, 1950.) W. Prager (Brown University). 30 pp. 1951. Price: 75 cents.

REPORTS

2. Iron and Steel Manufacture in Washington, Oregon, California, and Utah. Joseph Daniels. 69 pp. 1929.
3. Coal in Washington. Joseph Daniels. 17 pp. 1934.
4. Water Resources of Washington. Richard Gaines Tyler. 61 pp. 1938.
5. The Terminal Plan: An Improved System of Urban Transportation. Austin Vitruvius Eastman. 64 pp. 1938.
6. Chemical Utilization of the Subbituminous Coals of Washington. Lorentz A. Conradi. 83 pp. 1950.

TECHNICAL NOTES

3. The Theory of Fractional Parts Developed for Structural Beam-Column Members Preceded by an Elementary Discussion of Simple Beam and Column Design. Sybren Ruurd Tymstra. 32 pp. 1943.
4. Gaging Chart for Horizontal Cylindrical Tanks with Flat Heads or with Convex Heads. Sybren Ruurd Tymstra. 4 pp. 1944.
5. Gaging Chart for Cylindrical Tanks with Different Types of Heads. Sybren Ruurd Tymstra. 7 pp. 1945.
6. The Heat Pump for Residential Heating. G. S. Smith, H. Christensen, and A. Presson. 23 pp. 1948.

S. Sergev